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(54) **Title:** BEAM MANAGEMENT WITH BEAM REPORT SKIPPING INDICATIONS


(57) **Abstract:** A method of wireless communication by a user equipment (UE) comprises: performing a plurality of reference signal measurements associated with a plurality of beam directions; and transmitting, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.


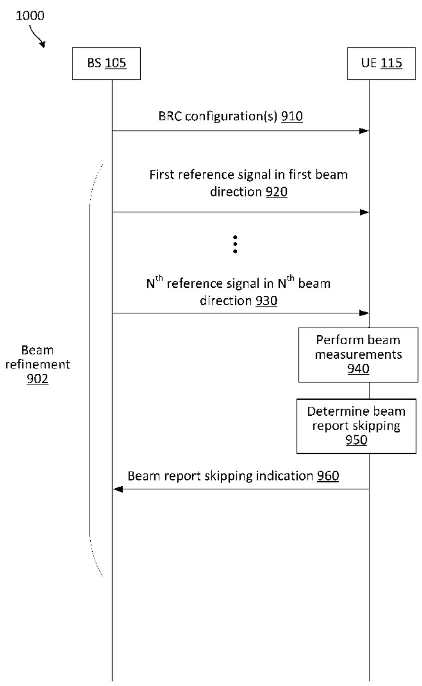


FIG. 9

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# BEAM MANAGEMENT WITH BEAM REPORT SKIPPING INDICATIONS

## INTRODUCTION

**[0001]** Wireless communications systems are widely deployed to provide various types of communication content such as voice, video, packet data, messaging, broadcast, and so on. These systems may be capable of supporting communication with multiple users by sharing the available system resources (e.g., time, frequency, and power). A wireless multiple-access communications system may include a number of base stations (BSs), each simultaneously supporting communications for multiple communication devices, which may be otherwise known as user equipment (UE).

**[0002]** To meet the growing demands for expanded mobile broadband connectivity, wireless communication technologies are advancing from the long term evolution (LTE) technology to a next generation new radio (NR) technology, which may be referred to as 5$^{th}$ Generation (5G). For example, NR is designed to provide a lower latency, a higher bandwidth or a higher throughput, and a higher reliability than LTE. NR is designed to operate over a wide array of spectrum bands, for example, from low-frequency bands below about 1 gigahertz (GHz) and mid-frequency bands from about 1 GHz to about 6 GHz, to high-frequency bands such as millimeter wave (mmWave) bands. NR is also designed to operate across different spectrum types, from licensed spectrum to unlicensed and shared spectrum. Spectrum sharing enables operators to opportunistically aggregate spectrums to dynamically support high-bandwidth services. Spectrum sharing can extend the benefit of NR technologies to operating entities that may not have access to a licensed spectrum.

**[0003]** As use cases and deployment scenarios continue to expand in wireless communication, extending NR from mmWave frequency ranges to sub-terahertz (sub-THz) frequency ranges may also yield benefits. For instance, sub-THz frequency spectrum can provide wide-bandwidth channels and ultra-high data rates.

## BRIEF SUMMARY OF SOME EXAMPLES

**[0004]** The following summarizes some aspects of the present disclosure to provide a basic understanding of the discussed technology. This summary is not an extensive overview of all contemplated features of the disclosure and is intended neither to identify key or critical elements of all aspects of the disclosure nor to delineate the scope of any or all aspects of the disclosure. Its sole purpose is to present some concepts of one or more aspects of the disclosure in summary form as a prelude to the more detailed description that is presented later.

**[0005]** For example, in an aspect of the disclosure, a method of wireless communication by a user equipment (UE), the method comprising: performing a plurality of reference signal measurements associated with a plurality of beam directions; and transmitting, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

**[0006]** In another aspect, a UE comprises: a memory device; a transceiver; and a processor in communication with the memory device and the transceiver. The UE is configured to perform a plurality of reference signal measurements associated with a plurality of beam directions; and transmit, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

**[0007]** In another aspect, a non-transitory, computer-readable memory comprises program code recorded thereon. The program code is executable by a processor of a UE to cause the UE to perform a plurality of reference signal measurements associated with a plurality of beam directions; and transmit, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

**[0008]** In another aspect, a UE comprises: means for performing a plurality of reference signal measurements associated with a plurality of beam directions; and means for transmitting, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

**[0009]** Other aspects, features, and embodiments of the present invention will become apparent to those of ordinary skill in the art, upon reviewing the following description of specific, exemplary embodiments of the present invention in conjunction with the accompanying figures. While features of the present invention may be discussed relative to certain embodiments and figures below, all embodiments of the present invention can include one or more of the advantageous features discussed herein. In other words, while one or more embodiments may be discussed as having certain advantageous features, one or more of such features may also be used in accordance with the various embodiments of the invention discussed herein. In similar fashion, while exemplary embodiments may be discussed below as device, system, or method embodiments it should be understood that such exemplary embodiments can be implemented in various devices, systems, and methods.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0010]** FIG. 1 illustrates a wireless communication network according to some aspects of the present disclosure.

**[0011]** FIG. 2 is a timing diagram illustrating a radio frame structure according to some aspects of the present disclosure

**[0012]** FIG. 3 illustrates a wireless communication network that supports directional beamforming according to some aspects of the present disclosure.

**[0013]** FIG. 4 is a sequence diagram illustrating a communication method with beam refinement operations according to some aspects of the present disclosure.

**[0014]** FIG. 5A illustrates a beam management procedure according to some aspects of the present disclosure.

**[0015]** FIG. 5B illustrates a beam management procedure according to some aspects of the present disclosure.

**[0016]** FIG. 5C illustrates a beam management procedure according to some aspects of the present disclosure.

**[0017]** FIG. 6A illustrates a beam report skipping scheme for a single beam report configuration (BRC) according to some aspects of the present disclosure.

**[0018]** FIG. 6B illustrates a beam report skipping scheme for a plurality of BRCs according to some aspects of the present disclosure.

**[0019]** FIG. 7A illustrates a beam report skipping scheme for indicating the timing resources associated with beam report skipping periods according to some aspects of the present disclosure.

**[0020]** FIG. 7B illustrates a beam report skipping scheme for indicating the timing resources associated with beam report skipping periods according to some aspects of the present disclosure.

**[0021]** FIG. 7C illustrates a beam report skipping scheme for indicating the timing resources associated with beam report skipping periods according to some aspects of the present disclosure.

**[0022]** FIG. 7D illustrates a beam report skipping scheme for indicating the timing resources associated with beam report skipping periods according to some aspects of the present disclosure.

**[0023]** FIG. 8A illustrates a beam report skipping scheme using beam report skipping indication resources according to some aspects of the present disclosure.

**[0024]** FIG. 8B illustrates a beam report skipping scheme using beam report skipping indication resources according to some aspects of the present disclosure.

**[0025]** FIG. 9 is a sequence diagram illustrating a beam report skipping indication scheme according to some aspects of the present disclosure.

**[0026]** FIG. 10 is a block diagram of an exemplary base station (BS) according to some aspects of the present disclosure.

**[0027]** FIG. 11 is a block diagram of an exemplary user equipment (UE) according to some aspects of the present disclosure.

**[0028]** FIG. 12 is a flow diagram of a wireless communication method according to some aspects of the present disclosure.

## DETAILED DESCRIPTION

**[0029]** The detailed description set forth below, in connection with the appended drawings, is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of the various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

**[0030]** This disclosure relates generally to wireless communications systems, also referred to as wireless communications networks. In various embodiments, the techniques and apparatus may be used for wireless communication networks such as code division multiple access (CDMA) networks, time division multiple access (TDMA) networks, frequency division multiple access (FDMA) networks, orthogonal FDMA (OFDMA) networks, single-carrier FDMA (SC-FDMA) networks, LTE networks, Global System for Mobile Communications (GSM) networks, $5^{th}$ Generation (5G) or new radio (NR) networks, as well as other communications networks. As described herein, the terms “networks” and “systems” may be used interchangeably.

**[0031]** An OFDMA network may implement a radio technology such as evolved UTRA (E-UTRA), Institute of Electrical and Electronics Engineers (IEEE) 802.11, IEEE 802.16, IEEE 802.20, flash-OFDM and the like. UTRA, E-UTRA, and GSM are part of universal mobile telecommunication system (UMTS). In particular, long term evolution (LTE) is a release of UMTS that uses E-UTRA. UTRA, E-UTRA, GSM, UMTS and LTE are described in documents provided from an organization named “3rd Generation Partnership Project” (3GPP), and cdma2000 is described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). These various radio technologies and standards are known or are being developed. For example, the 3rd Generation Partnership Project (3GPP) is a collaboration between groups of telecommunications associations that aims to define a globally applicable third generation (3G) mobile phone specification. 3GPP long term evolution (LTE) is a 3GPP project which was aimed at improving the UMTS mobile phone standard. The 3GPP may define specifications for the next generation of mobile networks, mobile systems, and mobile devices. The present disclosure is concerned with the evolution of wireless technologies from LTE, 4G, 5G, NR, and beyond with shared access to wireless spectrum between networks using a collection of new and different radio access technologies or radio air interfaces.

**[0032]** In particular, 5G networks contemplate diverse deployments, diverse spectrum, and diverse services and devices that may be implemented using an OFDM-based unified, air interface. In order to achieve these goals, further enhancements to LTE and LTE-A are considered in addition to development of the new radio technology for 5G NR networks. The 5G NR will be capable of scaling to provide coverage (1) to a massive Internet of things (IoTs) with a ultra-high density (e.g., ~1M nodes/km$^2$), ultra-low complexity (e.g., ~10s of bits/sec), ultra-low energy (e.g., ~10+ years of battery life), and deep coverage with the capability to reach challenging locations; (2) including mission-critical control with strong security to safeguard sensitive personal, financial, or classified information, ultra-high reliability (e.g., ~99.9999% reliability), ultra-low latency (e.g., ~ 1 ms), and users with wide ranges of mobility or lack thereof; and (3) with enhanced mobile broadband including extreme high capacity (e.g., ~ 10 Tbps/km$^2$), extreme data rates (e.g., multi-Gbps rate, 100+ Mbps user experienced rates), and deep awareness with advanced discovery and optimizations.

**[0033]** A 5G NR communication system may be implemented to use optimized OFDM-based waveforms with scalable numerology and transmission time interval (TTI). Additional features may also include having a common, flexible framework to efficiently multiplex services and features with a dynamic, low-latency time division duplex (TDD)/frequency division duplex (FDD) design; and with advanced wireless technologies, such as massive multiple input, multiple output (MIMO), robust millimeter wave (mmWave) transmissions, advanced channel coding, and device-centric mobility. Scalability of the numerology in 5G NR, with scaling of subcarrier spacing, may efficiently address operating diverse services across diverse spectrum and diverse deployments. For example, in various outdoor and macro coverage deployments of less than 3GHz FDD/TDD implementations, subcarrier spacing may occur with 15 kHz, for example over 5, 10, 20 MHz, and the like bandwidth (BW). For other various outdoor and small cell coverage deployments of TDD greater than 3 GHz, subcarrier spacing may occur with 30 kHz over 80/100 MHz BW. For other various indoor wideband implementations, using a TDD over the unlicensed portion of the 5 GHz band, the subcarrier spacing may occur with 60 kHz over a 160 MHz BW. Finally, for various deployments transmitting with mmWave components at a TDD of 28 GHz, subcarrier spacing may occur with 120 kHz over a 500 MHz BW.

**[0034]** The scalable numerology of the 5G NR facilitates scalable TTI for diverse latency and quality of service (QoS) requirements. For example, shorter TTI may be used for low latency and high reliability, while longer TTI may be used for higher spectral efficiency. The efficient multiplexing of long and short TTIs to allow transmissions to start on symbol boundaries. 5G NR also contemplates a self-contained integrated subframe design with UL/downlink scheduling information, data, and acknowledgement in the same subframe. The self-contained integrated subframe supports communications in unlicensed or contention-based shared spectrum, adaptive UL/downlink that may be flexibly configured on a per-cell basis to dynamically switch between UL and downlink to meet the current traffic needs.

**[0035]** Various other aspects and features of the disclosure are further described below. It should be apparent that the teachings herein may be embodied in a wide variety of forms and that any specific structure, function, or both being disclosed herein is merely representative and not limiting. Based on the teachings herein one of an ordinary level of skill in the art should appreciate that an aspect disclosed herein may be implemented independently of any other aspects and that two or more of these aspects may be combined in various ways. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth herein. In addition, such an apparatus may be implemented or such a method may be practiced using other structure, functionality, or structure and functionality in addition to or other than one or more of the aspects set forth herein. For example, a method may be implemented as part of a system, device, apparatus, and/or as instructions stored on a computer readable medium for execution on a processor or computer. Furthermore, an aspect may comprise at least one element of a claim.

**[0036]** Wireless communications at high frequencies, such as mmWave frequency ranges, may experience a high path-loss compared to lower frequency bands that are commonly used in conventional communication systems. To overcome the high path-loss, BSs and UEs may use beamforming techniques to form directional beams for communications. For instance, a BS and/or a UE may be equipped with one or more antenna panels or antenna arrays with antenna elements that can be configured to focus transmit signal energy and/or receive signal energy in a certain spatial direction and/or within a certain spatial angular sector or width. A beam used for such wireless communications may be referred to as an active beam, a best beam, or a serving beam. The active beam may initially be selected from reference beams and then refined over time.

**[0037]** As used herein, the term "transmission beam" may refer to a transmitter transmitting a beamformed signal in a certain spatial direction or beam direction and/or with a certain beam width covering a certain spatial angular sector. The transmission beam may have characteristics such as the beam direction and the beam width. As used herein, the term "reception beam" may refer to a receiver using beamforming to receive a signal from a certain spatial direction or beam direction and/or within a certain beam width covering a certain spatial angular sector. The reception beam may have characteristics such as the beam direction and the beam width. As used herein, the term "beam sweep" or "beam sweeping" may refer to a wireless communication device using sequentially each beam of a set of predefined beams (directing to a set of predefined spatial directions) for transmissions or receptions over a time period to cover a certain angular sector spatially.

**[0038]** In 5G, beam management is divided into three phases, which may be referred to as P1, P2, and P3. P1 is an initial beam pairing or beam discovery procedure performed prior to a connection is established between a BS and a UE. In this regard, a BS may implement periodic synchronization signal block (SSB) beam sweeping where the BS transmits SSBs across a set of beam directions (using a set of transmission beams at the BS) such that several relevant areas of a cell are reached. At the same time, a UE desiring to communicate with the BS may determine an optimal reception beam based on the SSB beams. In this regard, a UE may sweep across a set of beam directions (using a set of reception beams at the UE) to search for an appropriate beam direction for communicating with the BS. The UE may apply a different reception beam for each occurrence of the periodic SSBs. The UE may initiate a random access procedure with the BS using the determined reception beam. Upon completing the random access procedure, the UE and the BS may establish a connection with each other.

**[0039]** P2 is a beam refinement procedure performed between the BS and the UE while the UE is in a connected mode (e.g., with an established connection to the BS). During the P2 procedure, the BS may perform transmission beam sweep in a narrower angular sector than during the P1 procedure to refine the BS transmission beam. In this regard, the BS may transmit beam measurement signals (e.g., channel state information-reference signals (CSI-RSs)) using a set of narrow beams closest to the wide beam used for communicating with the UE during the P1 procedure. The UE may determine a received signal measurement (e.g., a layer 1-reference signal received power (L1-RSRP)) or other beam characteristics for each BS's transmission beam or DL beam using a fixed received beam (the optimal reception beam determined during P1). The UE may report the receive signal measurements to the BS, for example, in the form of a sorted list of signal measurements from a highest received signal power to a lowest received signal power or vice versa. In some other examples, the UE may report received signal measurements for DL beams that satisfies a certain threshold. In yet some other examples, the UE may report received signal measurements for N best DL beams (with the higher receive signal measurement among all the DL beams). The BS and/or the UE may select an optimal DL beam (BS transmission beam) for subsequent communications.

**[0040]** P3 is a beam refinement procedure performed between the BS and the UE while the UE is in a connected mode, for example, after performing the P2 procedure. During the P3 procedure, the BS may transmit reference signals (e.g., CSI-RSs) using the narrow transmission beam selected from P2 while the UE sweeps across a set of beam directions (using reception beams at the UE) to refine the UE reception beam. The UE may determine a signal measurement for each of the reception beams and select the reception beam with the highest signal measurement for subsequent communication with the BS.

**[0041]** In some aspects, it may be desirable or beneficial for the UE to skip one or more beam reporting occasions. Persons of skill in the art will understand that frequent beam reports can increase network overhead and reduce the time and frequency resources that may be used for other purposes. Frequent beam reporting may also increase power consumption at the reporting device and increase latency in communications. In some instances, a UE may detect changes in RSRP that are not likely to require beam management updates. For instance, the UE may move toward, or away from, the network node (e.g., gNB, TRP). This may involve a change in the strength of the serving beam, but may not result in the serving beam being less suitable or less optimal for communications than the other available beams. In some instances, even if the UE moves tangentially with respect to the network node, the overall ranking of the beams may not have changed. Accordingly, the beam reports transmitted by the UE in these circumstances may not result in improved mobility or beam management outcomes.

**[0042]** The present disclosure describes beam management and reporting mechanisms that allow a reporting device (e.g., UE, IoT device) to skip one or more beam reporting occasions. The mechanisms described herein include the reporting device transmitting, to the network, an indication that one or more beam reporting occasions will be skipped. By skipping the beam reporting, the UE may conserve power and make more efficient use of network resources.

**[0043]** FIG. 1 illustrates a wireless communication network 100 according to some aspects of the present disclosure. The network 100 may be a 5G network. The network 100 includes a number of base stations (BSs) 105 (individually labeled as 105a, 105b, 105c, 105d, 105e, and 105f) and other network entities. A BS 105 may be a station that communicates with UEs 115 (individually labeled as 115a, 115b, 115c, 115d, 115e, 115f, 115g, 115h, and 115k) and may also be referred to as an evolved node B (eNB), a next generation eNB (gNB), an access point, and the like. Each BS 105 may provide communication coverage for a particular geographic area. In 3GPP, the term “cell” can refer to this particular geographic coverage area of a BS 105 and/or a BS subsystem serving the coverage area, depending on the context in which the term is used.

**[0044]** A BS 105 may provide communication coverage for a macro cell or a small cell, such as a pico cell or a femto cell, and/or other types of cell. A macro cell generally covers a relatively large geographic area (e.g., several kilometers in radius) and may allow unrestricted access by UEs with service subscriptions with the network provider. A small cell, such as a pico cell, would generally cover a relatively smaller geographic area and may allow unrestricted access by UEs with service subscriptions with the network provider. A small cell, such as a femto cell, would also generally cover a relatively small geographic area (e.g., a home) and, in addition to unrestricted access, may also provide restricted access by UEs having an association with the femto cell (e.g., UEs in a closed subscriber group (CSG), UEs for users in the home, and the like). A BS for a macro cell may be referred to as a macro BS. A BS for a small cell may be referred to as a small cell BS, a pico BS, a femto BS or a home BS. In the example shown in FIG. 1, the BSs 105d and 105e may be regular macro BSs, while the BSs 105a-105c may be macro BSs enabled with one of three dimension (3D), full dimension (FD), or massive MIMO. The BSs 105a-105c may take advantage of their higher dimension MIMO capabilities to exploit 3D beamforming in both elevation and azimuth beamforming to increase coverage and capacity. The BS 105f may be a small cell BS which may be a home node or portable access point. A BS 105 may support one or multiple (e.g., two, three, four, and the like) cells.

**[0045]** The network 100 may support synchronous or asynchronous operation. For synchronous operation, the BSs may have similar frame timing, and transmissions from different BSs may be approximately aligned in time. For asynchronous operation, the BSs may have different frame timing, and transmissions from different BSs may not be aligned in time.

**[0046]** The UEs 115 are dispersed throughout the wireless network 100, and each UE 115 may be stationary or mobile. A UE 115 may also be referred to as a terminal, a mobile station, a subscriber unit, a station, or the like. A UE 115 may be a cellular phone, a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a tablet computer, a laptop computer, a cordless phone, a wireless local loop (WLL) station, or the like. In one aspect, a UE 115 may be a device that includes a Universal Integrated Circuit Card (UICC). In another aspect, a UE may be a device that does not include a UICC. In some aspects, the UEs 115 that do not include

UICCs may also be referred to as IoT devices or internet of everything (IoE) devices. The UEs 115a-115d are examples of mobile smart phone-type devices accessing network 100. A UE 115 may also be a machine specifically configured for connected communication, including machine type communication (MTC), enhanced MTC (eMTC), narrowband IoT (NB-IoT) and the like. The UEs 115e-115h are examples of various machines configured for communication that access the network 100. The UEs 115i-115k are examples of vehicles equipped with wireless communication devices configured for communication that access the network 100. A UE 115 may be able to communicate with any type of the BSs, whether macro BS, small cell, or the like. In FIG. 1, a lightning bolt (e.g., communication links) indicates wireless transmissions between a UE 115 and a serving BS 105, which is a BS designated to serve the UE 115 on the downlink (DL) and/or uplink (UL), desired transmission between BSs 105, backhaul transmissions between BSs, or sidelink transmissions between UEs 115.

**[0047]** In operation, the BSs 105a-105c may serve the UEs 115a and 115b using 3D beamforming and coordinated spatial techniques, such as coordinated multipoint (CoMP) or multi-connectivity. The macro BS 105d may perform backhaul communications with the BSs 105a-105c, as well as small cell, the BS 105f. The macro BS 105d may also transmits multicast services which are subscribed to and received by the UEs 115c and 115d. Such multicast services may include mobile television or stream video, or may include other services for providing community information, such as weather emergencies or alerts, such as Amber alerts or gray alerts.

**[0048]** The BSs 105 may also communicate with a core network. The core network may provide user authentication, access authorization, tracking, Internet Protocol (IP) connectivity, and other access, routing, or mobility functions. At least some of the BSs 105 (e.g., which may be an example of a gNB or an access node controller (ANC)) may interface with the core network through backhaul links (e.g., NG-C, NG-U, etc.) and may perform radio configuration and scheduling for communication with the UEs 115. In various examples, the BSs 105 may communicate, either directly or indirectly (e.g., through core network), with each other over backhaul links (e.g., X1, X2, etc.), which may be wired or wireless communication links.

**[0049]** The network 100 may also support mission critical communications with ultra-reliable and redundant links for mission critical devices, such as the UE 115e, which may be a drone. Redundant communication links with the UE 115e may include links from the macro BSs 105d and 105e, as well as links from the small cell BS 105f. Other machine type devices, such as the UE 115f (e.g., a thermometer), the UE 115g (e.g., smart meter), and UE 115h (e.g., wearable device) may communicate through the network 100 either directly with BSs, such as the small cell BS 105f, and the macro BS 105e, or in multi-step-size configurations by communicating with another user device which relays its information to the network, such as the UE 115f communicating temperature measurement information to the smart meter, the UE 115g, which is then reported to the network through the small cell BS 105f. The network 100 may also provide additional network efficiency through dynamic, low-latency TDD/FDD communications, such asV2V, V2X, C-V2X communications between a UE 115i, 115j, or 115k and other UEs 115, and/or vehicle-to-infrastructure (V2I) communications between a UE 115i, 115j, or 115k and a BS 105.

**[0050]** In some implementations, the network 100 utilizes OFDM-based waveforms for communications. An OFDM-based system may partition the system BW into multiple (K) orthogonal subcarriers, which are also commonly referred to as subcarriers, tones, bins, or the like. Each subcarrier may be modulated with data. In some instances, the subcarrier spacing between adjacent subcarriers may be fixed, and the total number of subcarriers (K) may be dependent on the system BW. The system BW may also be partitioned into subbands. In other instances, the subcarrier spacing and/or the duration of TTIs may be scalable.

**[0051]** In some aspects, the BSs 105 can assign or schedule transmission resources (e.g., in the form of time-frequency resource blocks (RB)) for downlink (DL) and uplink (UL) transmissions in the network 100. DL refers to the transmission direction from a BS 105 to a UE 115, whereas UL refers to the transmission direction from a UE 115 to a BS 105. The communication can be in the form of radio frames. A radio frame may be divided into a plurality of subframes or slots, for example, about 10. Each slot may be further divided into mini-slots. In a FDD mode, simultaneous UL and DL transmissions may occur in different frequency bands. For example, each subframe includes a UL subframe in a UL frequency band and a DL subframe in a DL frequency band. In a TDD mode, UL and DL transmissions occur at different time periods using the same frequency band. For example, a subset of the subframes (e.g., DL subframes) in a radio frame may be used for DL transmissions and another subset of the subframes (e.g., UL subframes) in the radio frame may be used for UL transmissions.

**[0052]** The DL subframes and the UL subframes can be further divided into several regions. For example, each DL or UL subframe may have pre-defined regions for transmissions of reference signals, control information, and data. Reference signals are predetermined signals that facilitate the communications between the BSs 105 and the UEs 115. For example, a reference signal can have a particular pilot pattern or structure, where pilot tones may span across an operational BW or frequency band, each positioned at a pre-defined time and a pre-defined frequency. For example, a BS 105 may transmit cell specific reference signals (CRSs) and/or channel state information – reference signals (CSI-RSs) to enable a UE 115 to estimate a DL channel. Similarly, a UE 115 may transmit sounding reference signals (SRSs) to enable a BS 105 to estimate a UL channel. Control information may include resource assignments and protocol controls. Data may include protocol data and/or operational data. In some aspects, the BSs 105 and the UEs 115 may communicate using self-contained subframes. A self-contained subframe may include a portion for DL communication and a portion for UL communication. A self-contained subframe can be DL-centric or UL-centric. A DL-centric subframe may include a longer duration for DL communication than for UL communication. A UL-centric subframe may include a longer duration for UL communication than for UL communication.

**[0053]** In some aspects, the network 100 may be an NR network deployed over a licensed spectrum. The BSs 105 can transmit synchronization signals (e.g., including a primary synchronization signal (PSS) and a secondary synchronization signal (SSS)) in the network 100 to facilitate synchronization. The BSs 105 can broadcast system information associated with the network 100 (e.g., including a master information block (MIB), remaining system information (RMSI), and other system information (OSI)) to facilitate initial network access. In some instances, the BSs 105 may broadcast the PSS, the SSS, and/or the MIB in the form of synchronization signal block (SSBs) over a physical broadcast channel (PBCH) and may broadcast the RMSI and/or the OSI over a physical downlink shared channel (PDSCH).

**[0054]** In some aspects, a UE 115 attempting to access the network 100 may perform an initial cell search by detecting a PSS from a BS 105. The PSS may enable synchronization of period timing and may indicate a physical layer identity value. The UE 115 may then receive a SSS. The SSS may enable radio frame synchronization, and may provide a cell identity value, which may be combined with the physical layer identity value to identify the cell. The PSS and the SSS may be located in a central portion of a carrier or any suitable frequencies within the carrier.

**[0055]** After receiving the PSS and SSS, the UE 115 may receive a MIB. The MIB may include system information for initial network access and scheduling information for RMSI and/or OSI. After decoding the MIB, the UE 115 may receive RMSI and/or OSI. The RMSI and/or OSI may include radio resource control (RRC) information related to random access channel (RACH) procedures, paging, control resource set (CORESET) for physical downlink control channel (PDCCH) monitoring, physical UL control channel (PUCCH), physical UL shared channel (PUSCH), power control, and SRS.

**[0056]** After obtaining the MIB, the RMSI and/or the OSI, the UE 115 can perform a random access procedure to establish a connection with the BS 105. In some examples, the random access procedure may be a four-step random access procedure. For example, the UE 115 may transmit a random access preamble and the BS 105 may respond with a random access response. The random access response (RAR) may include a detected random access preamble identifier (ID) corresponding to the random access preamble, timing advance (TA) information, a UL grant, a temporary cell-radio network temporary identifier (C-RNTI), and/or a backoff indicator. Upon receiving the random access response, the UE 115 may transmit a connection request to the BS 105 and the BS 105 may respond with a connection response. The connection response may indicate a contention resolution. In some examples, the random access preamble, the RAR, the connection request, and the connection response can be referred to as message 1 (MSG1), message 2 (MSG2), message 3 (MSG3), and message 4 (MSG4), respectively. In some examples, the random access procedure may be a two-step random access procedure, where the UE 115 may transmit a random access preamble and a connection request in a single transmission and the BS 105 may respond by transmitting a random access response and a connection response in a single transmission. The combined random access preamble and connection request in the two-step random access procedure may be referred to as a message A (MSG A). The combined random access response and connection response in the two-step random access procedure may be referred to as a message B (MSG B).

**[0057]** After establishing a connection, the UE 115 and the BS 105 can enter a normal operation stage, where operational data may be exchanged. For example, the BS 105 may schedule the UE 115 for UL and/or DL communications. The BS 105 may transmit UL and/or DL scheduling grants to the UE 115 via a PDCCH. The BS 105 may transmit a DL communication signal to the UE 115 via a PDSCH according to a DL scheduling grant. The UE 115 may transmit a UL communication signal to the BS 105 via a PUSCH and/or PUCCH according to a UL scheduling grant. The connection may be referred to as an RRC connection. When the UE 115 is actively exchanging data with the BS 105, the UE 115 is in an RRC connected state.

**[0058]** In an example, after establishing a connection with the BS 105, the UE 115 may initiate an initial network attachment procedure with the network 100. The BS 105 may coordinate with various network entities or fifth generation core (5GC) entities, such as an access and mobility function (AMF), a serving gateway (SGW), and/or a packet data network gateway (PGW), to complete the network attachment procedure. For example, the BS 105 may coordinate with the network entities in the 5GC to identify the UE, authenticate the UE, and/or authorize the UE for sending and/or receiving data in the network 100. In addition, the AMF may assign the UE with a group of tracking areas (TAs). Once the network attach procedure succeeds, a context is established for the UE 115 in the AMF. After a successful attach to the network, the UE 115 can move around the current TA. For tracking area update (TAU), the BS 105 may request the UE 115 to update the network 100 with the UE 115's location periodically. Alternatively, the UE 115 may only report the UE 115's location to the network 100 when entering a new TA. The TAU allows the network 100 to quickly locate the UE 115 and page the UE 115 upon receiving an incoming data packet or call for the UE 115.

**[0059]** In some aspects, the BS 105 may communicate with a UE 115 using hybrid automatic repeat request (HARQ) techniques to improve communication reliability, for example, to provide a ultra-reliable low-latency communication (URLLC) service. The BS 105 may schedule a UE 115 for a PDSCH communication by transmitting a DL grant in a PDCCH. The BS 105 may transmit a DL data packet to the UE 115 according to the schedule in the PDSCH. The DL data packet may be transmitted in the form of a transport block (TB). If the UE 115 decodes the DL data packet successfully, the UE 115 may transmit a HARQ acknowledgement (ACK) to the BS 105. Conversely, if the UE 115 fails to decode the DL transmission successfully, the UE 115 may transmit a HARQ negative-acknowledgement (NACK) to the BS 105. Upon receiving a HARQ NACK from the UE 115, the BS 105 may retransmit the DL data packet to the UE 115. The retransmission may include the same coded version of DL data as the initial transmission. Alternatively, the retransmission may include a different coded version of the DL data than the initial transmission. The UE 115 may apply soft-combining to combine the encoded data received from the initial transmission and the retransmission for decoding. The BS 105 and the UE 115 may also apply HARQ for UL communications using substantially similar mechanisms as the DL HARQ.

**[0060]** In some aspects, the network 100 may operate over a system BW or a component carrier (CC) BW. The network 100 may partition the system BW into multiple bandwidth parts (BWPs) (e.g., portions). A BS 105 may dynamically assign a UE 115 to operate over a certain BWP (e.g., a certain portion of the system BW). The assigned BWP may be referred to as the active BWP. The UE 115 may monitor the active BWP for signaling information from the BS 105. The BS 105 may schedule the UE 115 for UL or DL communications in the active BWP. In some aspects, a BS 105 may assign a pair of BWPs within the CC to a UE 115 for UL and DL communications. For example, the BWP pair may include one BWP for UL communications and one BWP for DL communications.

**[0061]** FIG. 2 is a timing diagram illustrating a radio frame structure 200 according to some aspects of the present disclosure. The radio frame structure 200 may be employed by BSs such as the BSs 105 and UEs such as the UEs 115 in a network such as the network 100 for communications. In particular, the BS may communicate with the UE using time-frequency resources configured as shown in the radio frame structure 200. In FIG. 2, the x-axes represent time in some arbitrary units and the y-axes represent frequency in some arbitrary units. The radio frame structure 200 includes a radio frame 201. The duration of the radio frame 201 may vary depending on the aspects. In an example, the radio frame 201 may have a duration of about ten milliseconds. The radio frame 201 includes M number of slots 202, where M may be any suitable positive integer. In an example, M may be about 10.

**[0062]** Each slot 202 includes a number of subcarriers 204 in frequency and a number of symbols 206 in time. The number of subcarriers 204 and/or the number of symbols 206 in a slot 202 may vary depending on the aspects, for example, based on the channel bandwidth, the subcarrier spacing (SCS), and/or the cyclic prefix (CP) mode. The CP mode specifies a CP length (a number of samples) for an OFDM symbol (e.g., the symbol 206). One subcarrier 204 in frequency and one symbol 206 in time forms one resource element (RE) 212 for transmission. A resource block (RB) 210 is formed from a number of consecutive subcarriers 204 in frequency and a number of consecutive symbols 206 in time.

**[0063]** In some aspects, a BS (e.g., BS 105 in FIG. 1) may schedule a UE (e.g., UE 115 in FIG. 1) for UL and/or DL communications at a time-granularity of slots 202 or mini-slots 208. Each slot 202 may be time-partitioned into K number of mini-slots 208. Each mini-slot 208 may include one or more symbols 206. The mini-slots 208 in a slot 202 may have variable lengths. For example, when a slot 202 includes N number of symbols 206, a mini-slot 208 may have a length between one symbol 206 and (N-1) symbols 206. In some aspects, a mini-slot 208 may have a length of about two symbols 206, about four symbols 206, or about seven symbols 206. In some examples, the BS may schedule UE at a frequency-granularity of a resource block (RB) 210 (e.g., including about 12 subcarriers 204 in 1 symbol, 2 symbols, …, 14 symbols).

**[0064]** In some aspects, the network 100 may operate over a high frequency band, for example, in a frequency range 2 (FR2) band, frequency range 4 (FR4) band, or a frequency range 2 (FR5) band. FR2 may refer to in mmWave frequency ranges. FR4 and FR5 may refer to sub-THz frequency ranges. To overcome the high path-loss at high frequency, the BSs 105 and the UEs 115 may communicate with each other using beamforming to generate directional beams for transmissions and/or receptions as shown in FIG. 3.

**[0065]** FIG. 3 illustrates a wireless communication network 300 that supports directional beamforming according to some aspects of the present disclosure. The network 300 may correspond to a portion of the network 100. FIG. 3 illustrates one BS 105 in communication with two TRPs 305 (shown as 305a and 305b) serving one UE 115 for simplicity of illustration and discussion, though it will be recognized that aspects of the present disclosure may scale to any suitable number of UEs 115 (e.g., about 2, 3, 4, 6, 7 or more) and/or TRPs 305 (e.g., about 2, 3 or more). In some instances, the TRPs 305 may also be referred to as radio heads. The TRPs 305 may implement at least some RF functionalities for over-the-air communications with the UE 115. In some instances, the BS 105 may also distribute some other functionalities such as baseband processing and/or protocol stack processing to the TRPs 305. In some instances, at least one of the TRPs 305 can be co-located with the BS 105. In some instances, both TRPs 305 can be located remotely from the BS 105. The BS 105 may schedule the TRPs 305 to communicate with the UE 115, for example, using SDM as will be discussed more fully below. The UE 115 may be similar to UEs 115. The TRPs 305 and the UE 115 may communicate with each other over a high-frequency band, for example, in a mmWave frequency range or a sub-THz range.

**[0066]** In FIG. 3, the TRPs 305 and the UE 115 may use beamforming techniques to generate transmit and/or reception beams for transmissions and/or receptions, respectively. In this regard, the TRP 305a may generate a set of transmission beams 310 (shown as 310a, 310b, and 310c) in a set of predefined beam directions. The TRP 305b may generate a set of transmission beams 320 (shown as 320a, 320b, and 320c) in a set of predefined beam directions. The UE 115 may generate a set of reception beams 330 (shown as 330a, 330b, and 330c) in a set of predefined beam directions. Additionally, each of the beams 310a-310c, 320a-320c, and 330a-330c may have a certain beam width covering a certain spatial angular sector. Although FIG. 3 illustrates three beams for each of the TRP 305a, TRP 305b, and the UE 115, it should be understood that in other examples each of the TRP 305a, TRP 305b, and the UE 115 can utilize a fewer beams or a greater number of beams for communication.

**[0067]** In the illustrated example of FIG. 3, the TRP 305a communicates with the UE 115 in a DL direction using the transmission beam 310c, and the TRP 305b communicates with the UE 115 in a DL direction using the transmission beam 320b. The UE 115 receives DL communications from the TRP 305a using the reception beam 330a and from the TRP 305b using the reception beam 330c. Although FIG. 3 illustrates the TRP 305a and the TRP 305b communicate with the UE 115 using beams that are along a line-of-sight (LOS) propagation path (e.g., between the beam 310c at the TRP 305a and the beam 330a at the UE 115, and between the beams 320b at the TRP 305b and the beam 330c at the UE 115), it should be understood that in other examples the TRP 305a and/or the TRP 305b may use a transmission beam that is non-line-of-sight (NLOS) (e.g., reflected off a reflector or scatterer in the environment) to communicate with the UE 115 for communication.

**[0068]** In some aspects, each of the TRP 305a, TRP 305b, and the UE 115 may have one or more antenna panels or one or more antenna arrays each comprising a plurality of antenna elements. The antenna elements can be individually controlled to adjust the gain and/or phase such that an antenna array or an antenna panel can be configured to focus a transmit signal in a certain beam direction and/or to focus in a certain beam direction for receiving a signal.

**[0069]** In some aspects, depending on the environment (e.g., reflectors and/or scatterers), the TRP 305a and/or the TRP 305b may communicate with the UE 115 in a UL direction in the same beam direction. In other words, the TRP 305a may generate a reception beam in the same beam direction as the beam 310c for receiving UL communications from the UE 115, and the TRP 305b may generate a reception beam in the same beam direction as the beam 320b for receiving UL communications from the UE 115. Similarly, the UE 115 may generate a transmission beam in the same beam direction as the beam 330a for transmitting UL communications to the TRP 305a, and may generate a transmission beam in the same beam direction as the beam 330c for transmitting UL communications to the TRP 305b. In some other aspects, the TRP 305a and the UE 115 may communicate with each other in different beam directions for UL and for DL. Similarly, the TRP 305b and the UE 115 may communicate with each other in different beam directions for UL and for DL.

**[0070]** In some aspects, prior to exchanging data between a UE (e.g., the UEs 115) and a BS (e.g., the BSs 105), the UE and/or the BS may determine an optimal UL-DL beam pair for communications. In this regard, the BS and the UE may perform an initial beam pair selection. Subsequently, the BS and the UE may refine the initial beam selection as will be discussed more fully below with reference to FIGS. 4 and 5.

**[0071]** FIG. 4 is a sequence diagram illustrating a communication method 400 with beam refinement operations according to some aspects of the present disclosure. The method 400 may be performed by wireless networks, such as the networks 100 and/or 300 communicating over a high-frequency band, such as a mmWave band or a sub-THz band. In this regard, the method 400 is performed by a BS 105 and a UE 115. In some aspects, the BS 105 may utilize one or more components, such as the processor 1102, the memory 1104, the beam module 1108, the transceiver 1110, the modem 1112, and the one or more antennas 1116 shown in FIG. 11, to execute the actions of the method 400. The UE 115 may utilize one or more components, such as the processor 1202, the memory 1204, the beam module 1208, the transceiver 1210, the modem 1212, and the one or more antennas 1216 shown in FIG. 12, to execute the actions of the method 400.

**[0072]** At action 410, the BS 105 and the UE 115 establish a communication with each other. In this regard, the BS 105 may transmit SSBs by sweeping across a set of DL beams (e.g., the beams 310 and/or 320) in a set of predefined beam directions similar to the P1 procedure described above. In some instances, the BS 105 may utilize TRPs (e.g., the TRPs 305) to communicate with the UE 115. For simplicity of illustration and discussion, the method 400 is discussed from the perspective of a single TRP co-located with the BS 105 or at a remote location from the BS 105. However, similar communications may also occur for other TRPs that are in communication with the BS 105.

The BS 105 may repeat the SSB transmissions at a certain time interval (e.g., periodically) in the set of beam directions to allow the UE 115 to perform initial network access. In some instances, each beam and its corresponding characteristics may be identified by a beam index. For instance, each SSB may include an indication of a beam index corresponding to the beam used for the SSB transmission. At the same time, the UE 115 may determine signal measurements, such as reference signal received power (RSRP) and/or reference signal received quality (RSRQ), for the SSBs at the different beam directions. In some aspects, the UE 115 may also sweep across a set of reception beams (e.g., the beams 330) when monitoring for SSBs from the BS 105. The UE 115 may apply a different reception beam for each occurrence of the periodic SSBs. The UE 115 may determine an optimal transmit-reception beam pair (with the highest RSRP or highest RSRQ) for establishing the communication with the BS 105. The optimal transmit-reception beam pair may include a best DL beam or transmission beam from the BS 105 and a best reception beam at the UE. The UE 115 may indicate the selection by transmitting a PRACH signal (e.g., MSG1) using PRACH resources associated with the selected beam direction. For instance, the SSB transmitted in a particular beam direction may indicate PRACH resources that may be used by a UE 115 to communicate with the BS 105 in that particular beam direction. After selecting the best DL beam, the UE 115 may complete the random access procedure (e.g., the 4-step random access or the 2-step random access) and establish a connection (e.g., an RRC connection) with the BS 105.

**[0073]** At action 420, after establishing the connection, the BS 105 and the UE 115 may perform a beam refinement procedure similar to the P2 procedure described above to refine a BS beam selection (DL beam selection). In this regard, the BS 105 may transmit beam measurement signals or reference signals (e.g., CSI-RSs) by sweeping narrower beams (e.g., the beams 520 of FIG. 5) over a narrower angular range, for example, close to the wide beam used for establishing the communication at action 410. The UE 115 may determine a received signal measurement (e.g., RSRP and/or RSRQ) for each of BS 105's narrow transmission beam using a fixed received beam (the optimal reception beam determined at action 410). The UE 115 may report the receive signal measurements to the BS, for example, in the form of a sorted list of signal measurements from a highest received signal power to a lowest received signal power or vice versa. In some other examples, the UE 115 may report received signal measurements for DL beams that exceeds a certain threshold. In yet some other examples, the UE 115 may report received signal measurements for N best DL beams (with the higher receive signal measurement among all the DL beams). The BS 105 and/or the UE 115 may select an optimal transmission beam of the BS 105 for subsequent communications.

**[0074]** In some aspects, the beam refinement may also include refining a reception beam selection at the UE 115 similar to the P3 procedure described above. In some aspects, beam refinement (P2 and/or P3) may be performed on-demand and may rely on aperiodic CSI-RSs. For instance, upon beam degradation (e.g., beam quality metrics falling below a threshold), one or more of P2 or P3 may be used to select new or better transmission and/or reception beams.

**[0075]** Figs. 5A-5C are diagrams illustrating examples 500, 510, and 520 of beam management procedures, respectively, in accordance with the present disclosure. As shown in Figs. 5A-5C, examples 500, 510, and 520 include a UE 120 in communication with a network node 110 in a wireless network (e.g., wireless network 100). However, the devices shown in Figs. 5A-5C are provided as examples, and the wireless network may support communication and beam management between other devices (e.g., between a UE 120 and a network node 110 or TRP, between a mobile termination node and a control node, between an IAB child node and an IAB parent node, and/or between a scheduled node and a scheduling node). In some aspects, the UE 120 and the network node 110 may be in a connected state (e.g., an RRC connected state).

**[0076]** The network node 110 may transmit a synchronization signal block (SSB) to UEs. The SSB may carry information used by a UE for initial network acquisition and synchronization, such as a PSS, an SSS, a physical broadcast channel (PBCH), and a PBCH DMRS. An SSB is sometimes referred to as a synchronization signal/PBCH (SS/PBCH) block. In some aspects, the network node 110 may transmit multiple SSBs on multiple corresponding beams, and the SSBs may be used for beam selection.

**[0077]** As shown in Fig. 5A, example 500 may include a network node 110 (e.g., one or more network node devices such as an RU, a DU, and/or a CU, among other examples) and a UE 120 communicating to perform beam management using CSI-RSs. Example 500 depicts a first beam management procedure (e.g., P1 beam management). The first beam management procedure may be referred to as a beam selection procedure, an initial beam acquisition procedure, a beam sweeping procedure, a cell search procedure, and/or a beam search procedure. As shown in Fig. 5A and example 500, CSI-RSs may be configured to be transmitted from the network node 110 to the UE 120. The CSI-RSs may be configured to be periodic (e.g., using RRC signaling), semi-persistent (e.g., using media access control (MAC) control element (MAC-CE) signaling), and/or aperiodic (e.g., using DCI).

**[0078]** The first beam management procedure may include the network node 110 performing beam sweeping over multiple Tx beams. The network node 110 may transmit a CSI-RS using each transmit beam for beam management. To enable the UE 120 to perform Rx beam sweeping, the network node may use a transmit beam to transmit (e.g., with repetitions) each CSI-RS at multiple times within the same RS resource set so that the UE 120 can sweep through receive beams in multiple transmission instances. For example, if the network node 110 has a set of N transmit beams and the UE 120 has a set of M receive beams, the CSI-RS may be transmitted on each of the N transmit beams M times so that the UE 120 may receive M instances of the CSI-RS per transmit beam. In other words, for each transmit beam of the network node 110, the UE 120 may perform beam sweeping through the receive beams of the UE 120. As a result, the first beam management procedure may enable the UE 120 to measure a CSI-RS on different transmit beams using different receive beams to support selection of network node 110 transmit beams/UE 120 receive beam(s) beam pair(s). The UE 120 may report the measurements to the network node 110 to enable the network node 110 to select one or more beam pair(s) for communication between the network node 110 and the UE 120. While example 500 has been described in connection with CSI-RSs, the first beam management process may also use SSBs for beam management in a similar manner as described above.

**[0079]** As shown in Fig. 5B, example 510 may include a network node 110 and a UE 120 communicating to perform beam management using CSI-RSs. Example 510 depicts a second beam management procedure (e.g., P2 beam management). The second beam management procedure may be referred to as a beam refinement procedure, a network node beam refinement procedure, a TRP beam refinement procedure, and/or a transmit beam refinement procedure. As shown in Fig. 5B and example 510, CSI-RSs may be configured to be transmitted from the network node 110 to the UE 120. The CSI-RSs may be configured to be aperiodic (e.g., using DCI). The second beam management procedure may include the network node 110 performing beam sweeping over one or more transmit beams. The one or more transmit beams may be a subset of all transmit beams associated with the network node 110 (e.g., determined based at least in part on measurements reported by the UE 120 in connection with the first beam management procedure). The network node 110 may transmit a CSI-RS using each transmit beam of the one or more transmit beams for beam management. The UE 120 may measure each CSI-RS using a single (e.g., a same) receive beam (e.g., determined based at least in part on measurements performed in connection with the first beam management procedure). The second beam management procedure may enable the network node 110 to select a best transmit beam based at least in part on measurements of the CSI-RSs (e.g., measured by the UE 120 using the single receive beam) reported by the UE 120.

**[0080]** As shown in Fig. 5C, example 520 depicts a third beam management procedure (e.g., P3 beam management). The third beam management procedure may be referred to as a beam refinement procedure, a UE beam refinement procedure, and/or a receive beam refinement procedure. As shown in Fig. 5C and example 520, one or more CSI-RSs may be configured to be transmitted from the network node 110 to the UE 120. The CSI-RSs may be configured to be aperiodic (e.g., using DCI). The third beam management process may include the network node 110 transmitting the one or more CSI-RSs using a single transmit beam (e.g., determined based at least in part on measurements reported by the UE 120 in connection with the first beam management procedure and/or the second beam management procedure). To enable the UE 120 to perform receive beam sweeping, the network node may use a transmit beam to transmit (e.g., with repetitions) CSI-RS at multiple times within the same RS resource set so that UE 120 can sweep through one or more receive beams in multiple transmission instances. The one or more receive beams may be a subset of all receive beams associated with the UE 120 (e.g., determined based at least in part on measurements performed in connection with the first beam management procedure and/or the second beam management procedure). The third beam management procedure may enable the network node 110 and/or the UE 120 to select a best receive beam based at least in part on reported measurements received from the UE 120 (e.g., of the CSI-RS of the transmit beam using the one or more receive beams).

**[0081]** Similar beam management procedures may be used for sidelink beam management operations between UEs in accordance with the present disclosure. Sidelink beam management operations may include initial beam-pairing or beamforming, beam fine tuning, beam maintenance, and beam failure recovery. Beam fine tuning may involve selection of a beam direction and limited beam sweeping around the beam direction. The limited beam sweeping may use narrower beams and/or use more granularity in beam directions.

**[0082]** As indicated above, Figs. 5A-5C are provided as examples of beam management procedures. Other examples of beam management procedures may differ from what is described with respect to Figs. 5A-5C. For example, the UE 120 and the network node 110 (or UEs in sidelink communication) may perform the third beam management procedure before performing the second beam management procedure, and/or the UE 120 and the network node 110 (or UEs in sidelink communication) may perform a similar beam management procedure to select a UE transmit beam and/or UE receive beam. Further, the beam management procedures described in Figs. 5A-5C may be modified in one or more ways without departing from the scope of the present disclosure.

**[0083]** The beam management procedures described above involve the UE transmitting beam reports in response to detected changes in signal strength or quality (e.g., RSRP, RSRQ, etc.). Persons of skill in the art will understand that frequent beam reports can increase network overhead and reduce the time and frequency resources that may be used for other purposes. Frequent beam reporting may also increase power consumption at the reporting device and increase latency in communications. In some instances, a UE may detect changes in RSRP that are not likely to require beam management updates. For instance, the UE may move toward, or away from, the network node (e.g., gNB, TRP). This may involve a change in the strength of the serving beam, but may not result in the serving beam being less suitable or less optimal for communications than the other available beams. In some instances, even if the UE moves tangentially with respect to the network node, the overall ranking of the beams may not have changed. Accordingly, the beam reports transmitted by the UE in these circumstances may not result in improved mobility or beam management outcomes.

**[0084]** The present disclosure describes beam management and reporting mechanisms that allow a reporting device (e.g., UE, IoT device) to skip one or more beam reporting occasions. The mechanisms described herein include the reporting device transmitting, to the network, an indication that one or more beam reporting occasions will be skipped. The indication may be carried in UCI. The UCI may indicate the time and/or frequency resources associated with the one or more skipped beam reporting occasions. The indicated resources may be expressed as a number of slots, a number of symbols, and/or a number of beam reporting occasions to be skipped. In other aspects, the indicated resources may be expressed at least in part by one or more beam report configurations associated with the one or more skipped beam reporting occasions. In some aspects, the reporting device may determine to skip one or more beam reporting occasions based on a comparison of an updated signal strength of a serving beam to an updated signal strength of an least one other beam. In other aspects, the reporting device may determine to skip one or more beam reporting occasions based on an updated ranking of a plurality of beams or beam directions. For instance, if there is no change in the ranking of the plurality of beams or beam directions, the reporting device may determine to skip one or more beam reporting occasions. In another example, if the current serving beam remains the top-ranked beam, or within the top-ranked N beams, the reporting device may determine to skip one or more beam reporting occasions. Thus, the reporting device may relax or reduce beam reporting transmissions, thereby making more efficient use of power and network resources.

**[0085]** FIGS. 6A-8B illustrate various beam reporting schemes and mechanisms in which a reporting device, such as a UE or an IoT device, skips one or more beam reporting occasions based on reference signal measurements associated with a plurality of beam directions. In the beam reporting schemes and mechanisms of FIGS. 6A-8B, the reporting device may transmit a beam report skipping indication to a network node (e.g., gNB, TRP) indicating that one or more beam reporting occasions will be skipped. The beam report skipping indication may be transmitted in a beam reporting occasion, a beam skipping indication, or some other configured time resource in which a beam report skipping indication may be transmitted by the reporting device and received by the network node. The beam report skipping indication may indicate the one or more skipped beam reporting occasions in various ways, including an indication of one or more beam report configurations (BRCs) and/or component carriers (CCs) associated with the skipped beam reporting occasions, an indication of one or more slots or symbols associated with the skipped beam reporting occasions, or any suitable combination thereof. In some instances, the beam report skipping indication applies to a single beam reporting occasion. In other instances, the beam report skipping indication applies to a plurality of beam reporting occasions. Each of these aspects will be described more detail with respect to the specific Figures in the description below.

**[0086]** Referring again to BRCs and CCs, a beam report skipping indication may be associated with a single BRC in a single CC, or with multiple BRCs in one or more CCs. In this regard, FIGS. 6A and 6B illustrate beam reporting schemes 600, 650 in which one or more beam reporting occasions 602 corresponding to one or more BRCs are skipped. The schemes 600, 650 may be performed by a beam reporting device, such as a UE, an IoT device, or any other suitable device configured to perform beam management procedures and transmit beam reports. For the purposes of the forgoing description, the schemes 600, 650 will be described as being performed by a UE, however it will be understood that any suitable wireless communication device configured to perform beam reporting and beam management may perform the schemes 600, 650. In the schemes 600, 650, each of the individual boxes 606 may correspond to a slot, a symbol, a subframe, and/or any other suitable timing parameter.

**[0087]** In FIG. 6A, a single beam reporting configuration (BRC) is shown corresponding to BRC ID1. The BRC is configured for a first component carrier (CC), shown as CC1. The BRC is also associated with a first periodicity (periodicity 1). The BRC establishes, or is associated with, a plurality of beam reporting occasions 602. The periodicity 1 may refer to the periodicity of the beam reporting occasions 602 in terms of a number of slots. In other aspects, the periodicity 1 may refer to the periodicity of the beam reporting occasions 602 in terms of a number of symbols. In other aspects, the periodicity 1 may be in terms of any suitable timing parameter, including mini slots, subframes, microseconds, and/or any other type of timing parameter.

**[0088]** In the scheme 600, the periodicity 1 is four boxes 606, which may correspond to four slots, four symbols, or four of any other suitable timing parameter. Some of the beam reporting occasions 602 are skipped, and referred to ask “skipped BR occasions” 604. For instance, the UE may transmit, in a first BR occasion 608, a beam report skipping indication indicating that one or more beam reporting occasions 602 will be skipped. The beam report skipping indication may be associated with the BRC ID1 and the CC1 in the scheme 600. In some aspects, the beam report skipping indication may further indicate a number of beam reporting occasions to be skipped. As described further below, the beam report skipping indication may indicate a length of a beam report skipping period (e.g., in number of slots, in number of symbols, in number of beam reporting occasions, etc.). The beam report skipping indication may also indicate a timing offset (e.g., in number of slots, in number of symbols, in number of beam reporting occasions, etc.) from the beam report skipping indication to the beginning of the beam report skipping period. As shown in the scheme 600, a second beam report indication may be transmitted in a second BR occasion 610. The second beam report skipping indication may indicate that the following two BR occasions 602 will be skipped. Accordingly, two skipped BR occasions 604 are shown following the second BR occasion 610.

**[0089]** In some aspects, the beam report skipping indication may be transmitted in uplink control information (UCI). For instance, the UE may transmit one or more UCIs including the beam report skipping indication, and the beam report skipping indication may indicate the corresponding BRC ID and/or the corresponding CC index. In another aspect, the beam report skipping indication may indicate an index or value corresponding to a configured list or table. For instance, the UE may be configured by RRC with a table of BRC IDs, CCs, and/or any other suitable parameter. The beam report skipping indication may indicate an index or value corresponding to the BRC ID1, CC1, and/or periodicity 1. For instance, the index in the beam report skipping indication may be associated with a row or entry in the RRC-configured table.

**[0090]** FIG. 6B illustrates another scheme 650 for beam reporting and beam report skipping. The scheme 600 may be similar or identical in some aspects to the scheme 600 shown in FIG. 6A. For instance, the scheme 650 also includes a plurality of BR occasions 602 and a plurality of skipped BR occasions 604. Each BR occasion is associated with a box 606, which may be a slot, a symbol, a subframe, a mini-slot, or any other suitable timing parameter. While the scheme 600 in FIG. 6A shows a mechanism for indicating skipped beam report occasions for a single BRC in a single CC, the scheme 650 contemplates a mechanism for indicating skipped beam report occasions for a plurality of BRCs in one or more CCs. In particular, the UE is configured with at least a first BRC (BRC ID1) in CC1, a second BRC (BRC ID2) also in CC1, and a third BRC (BRC ID3) in CC2. Each BRC is associated with a periodicity, shown as periodicity 1, periodicity 2, and periodicity 3. In some aspects, one or more of the periodicities 1, 2, and 3, may be the same periodicity. For instance, periodicity 2 and periodicity 3 may correspond to a same periodicity. In other aspects, periodicities 1, 2, and 3 may all be different. In the illustrated example, periodicity 2 and periodicity 3 are the same in terms of the time-domain spacing of the BR occasions 602 in number of slots, but may differ in relative offset, such that each corresponding BR occasion of BRC ID2 is offset from each BR occasion of BRC ID3 by at least one box 606 (e.g., one slot, one symbol).

[0091] In the scheme 650, the UE may transmit, in a first BR occasion 612 in CC1, a beam report skipping indication indicating that one or more beam reporting occasions 602 will be skipped. The beam report skipping indication may be associated with the BRC ID1 and the CC1 in the scheme 650. However, in other aspects, the UE may transmit the beam report skipping indication in CC2 and/or any other suitable CC for which a BRC is configured. The beam report skipping indication may indicate each BRC and/or CC for which one or more beam reporting occasions 602 will be skipped. In some aspects, the beam report skipping indication may further indicate a number of beam reporting occasions to be skipped. The beam report skipping indication may indicate a length of a beam report skipping period (e.g., in number of slots, in number of symbols, in number of beam reporting occasions, etc.). The beam report skipping indication may also indicate a timing offset (e.g., in number of slots, in number of symbols, in number of beam reporting occasions, etc.) from the beam report skipping indication to the beginning of the beam report skipping period. In some aspects, a second beam report indication may be transmitted in a second BR occasion 614. The second beam report skipping indication may indicate that the following two BR occasions 602 will be skipped in CC1 for BRC ID1, a single BR occasion for BRC ID2, and a single BR occasion for BRC ID3 in CC2.

[0092] In some aspects, the beam report skipping indication may be transmitted in UCI. For instance, the UE may transmit one or more UCIs including the beam report skipping indication, and the beam report skipping indication may indicate the corresponding BRC IDs and/or the corresponding CC indices for the skipped beam reporting occasions. In another aspect, the beam report skipping indication may indicate an index or value corresponding to a configured list or table. For instance, the UE may be configured by RRC with a table of BRC IDs, CCs, and/or any other suitable parameter. The beam report skipping indication may indicate an index or value corresponding to one or more of the BRCs, including BRC ID1, BRC ID2, and/or BRC ID3. The indicated value may also correspond to a CC index or value, such as CC1 and/or CC2. The indicated value may also correspond to a periodicity for the BRC, such as periodicity 1, periodicity 2, and/or periodicity 3. For instance, the index in the beam report skipping indication transmitted in the beam reporting occasion 614 may be associated with a row or entry in the RRC-configured table that indicates BRC ID1 in CC1, BRC ID2 in CC1, and BRC ID3 in CC2.

[0093] As mentioned above the beam report skipping indications may specify or indicate the beam report occasions to be skipped by indicating one or more of a length of time or a time offset associated with the skipped beam reporting occasions. The indicated length of time and/or time offset may be indicated as a number of slots, a number of symbols, a number of beam reporting occasions, and/or any other suitable mechanism for time indication. FIGS. 7A-7D illustrate various schemes or mechanisms for indicating or specifying one or more beam reporting occasions to be skipped with one or more beam report skipping indications.

**[0094]** The schemes 700, 710, 720, and 730 of FIGS. 7A-7D may be performed by a beam reporting device, such as a UE, an IoT device, or any other suitable device configured to perform beam management procedures and transmit beam reports. For the purposes of the forgoing description, the schemes 700, 710, 720, and 730 will be described as being performed by a UE, however it will be understood that any suitable wireless communication device configured to perform beam reporting and beam management may perform the schemes 700, 710, 720, and 730. Similar to FIGS. 6A and 6B, in the schemes 700, 710, 720, and 730, each of the individual boxes may correspond to a slot, a symbol, a subframe, and/or any other suitable timing parameter. For the purposes of the forgoing disclosure, the individual boxes will be described as slots. However, it will be understood that each box may represent one or more symbols, one or more subframes, one or more mini-slots, and/or any other suitable unit of time.

**[0095]** In the scheme 700 of FIG. 7A, the UE transmits a UCI 702 in a first BR occasion, with the UCI carrying, including, or otherwise indicating a first beam report skipping indication. The beam report skipping indication indicates the timing parameters for a skipped BR occasion in terms of slots. Accordingly, the beam report skipping indication indicates that the period of time associated with the skipped BR occasion is offset from the UCI slot by three slots, and has a length of one slot. In accordance with the first beam report skipping indication, the UE skips the BR occasion that begins three full slots after the UCI slot, and is within the one slot length. The UE transmits a second UCI 704 carrying, including, or otherwise indicating a second beam report skipping occasion. The second beam report skipping indication indicates an offset of three slots, but a beam report skipping duration of five slots. As shown in FIG. 7A, two BR occasions fall within the offset 5-slot period. Thus, the UE skips the following two beam reporting occasions. It will be understood that the scheme 700 for indicating skipped BR occasions may be performed in conjunction with any of the schemes above, including the schemes 600 and 650 shown in FIGS. 6A and 6B. For instance, the indications provided in the beam report skipping indication may apply to one or more BRCs and/or one or more CCs. In some aspects, the beam report skipping indication may indicate a timing offset and/or a length for each BRC and/or each CC. In other aspects, the beam report skipping indication may indicate a timing offset and/or a length that applies across multiple BRCs and/or across multiple CCs. For instance, the beam report skipping indication may indicate that any beam reporting occasions for any BRC and/or CC that fall within the indicated timing parameters are to be skipped.

**[0096]** In the scheme 710, the UE indicates the skipped BR occasions in terms of numbers of BR occasions. For instance, the UE transmits a first UCI 712 carrying a first beam report skipping indication. The beam report skipping indication indicates a beam report skipping period that begins after a timing offset of two beam reporting occasions, and lasts for two beam reporting occasions. Further, the UE transmits a second UCI 714 carrying a second beam report skipping indication. The second beam report skipping indication indicates a beam report skipping period that begins after a timing offset of one BR occasion, and lasts for one BR occasion. Thus, the UE skips the single BR occasion following the BR occasion in which the UCI 714 is transmitted. In this regard, it will be understood that an offset of one BR occasion refers to the BR occasion that immediately follows the BR occasion in which the UCI 714 is transmitted. In other aspects, a timing offset of one BR occasion may indicate a time period that begins after one full BR occasion that follows the BR occasion in which the UCI 714 is transmitted. As with the scheme 700, the scheme 710 may be performed in conjunction with either of the schemes 600, 650 shown in FIGS. 6A and 6B.

**[0097]** In the schemes 700 and 710, the UE may dynamically indicate the timing offset associated with the skipped beam reporting occasions. In other aspects, the UE may indicate one or more timing parameters of the skipped BR occasions based on configured or fixed timing parameters. For instance, the UE may be configured by RRC with a timing offset for the skipped BR occasions. In another aspect, the UE may be configured with a fixed timing offset for the skipped BR occasions. In other aspects, the UE may be configured (e.g., RRC or fixed configuration) with a length of time associated with the skipped BR occasions. The schemes 720 and 730 shown in FIGS. 7C and 7D illustrate mechanisms for beam report skipping indications in which the reporting device transmits beam report skipping indications associated with or based on one or more configured timing offsets. For instance, in the scheme 720 of FIG. 7C, the UE transmits a first UCI 722 including a first beam report skipping indication. The first beam report skipping indication indicates a length of two slots. Further, the UE is configured with a timing offset of two slots. Thus, the beam report skipping period begins after the configured period of two slots and lasts for the length of two slots, as indicated in the first UCI 722. In the illustrated example, the beam report skipping period with the configured or fixed offset covers one BR occasion to be skipped. Further, a second UCI 724 is transmitted carrying a second beam report skipping indication. The second beam report skipping indication indicates a length of six slots. Thus, the beam report skipping period begins after the configured period of two slots following the slot of the second UCI 724, and lasts for six slots. This beam report skipping period covers the two BR occasions that follow the second UCI 724.

**[0098]** In another example, the UE may indicate the length of the beam report skipping period as a number of BR occasions, as similarly shown in the scheme 710 shown in FIG. 7B. However, the

UE may be configured with an offset based on a number of slots. Thus, the scheme 730, the UE transmits a first beam report skipping indication in a first UCI 732, with the first beam report skipping indication indicating a length of one BR occasion. The UE is configured with a timing offset of two slots. Thus, the UE skips the BR occasions in the beam report skipping period that begins after the configured offset of two slots, and includes the length of one BR occasion. The UE transmits a second beam report skipping indication in a second UCI 734, with the second beam report skipping indication indicating a length of two BR occasions. Thus, the UE skips the two BR occasions that begin after the configured offset of two slots. In other aspects, it will be understood that the UE may be configured with an offset in numbers of BR occasions. Further, it will be understood that the schemes 700, 710, 720, and 730 may be performed by indicating the timing offset and/or length as a number of symbols, a number of subframes, a number of mini-slots, and/or any other suitable unit of time.

**[0099]** In another aspect of the present disclosure, a reporting device may be configured to transmit beam report skipping indications less frequently than the periodicity of the corresponding BRC. For instance, if the UE is configured with a BRC having a beam reporting occasion periodicity of N slots, the UE may be configured to transmit beam report skipping indications with a periodicity of 2N slots, 3N slots, 4N slots, or any other suitable periodicity. In some aspects, reducing the periodicity of beam report skipping indications may reduce network overhead caused by the beam report skipping indications. In still another aspect of the present disclosure, the UE may be configured with multiple sets of resources, where some are suitable for or configured for communicating beam reports only, some are suitable for or configured for communicating beam report skipping indications only, and some are suitable for or configured for communicating either beam reports, beam report skipping indications, or both. FIGS. 8A and 8B illustrate schemes for beam report skipping indications in which a UE is configured to transmit beam report skipping indications with a periodicity that is different from the periodicity of the beam reporting occasions.

**[0100]** Referring to the scheme 800 of FIG. 8A, a UE is configured with a BRC associated with a plurality of BR occasions. The BR occasions may be associated with or based on a periodicity of N slots, or N symbols, for example. Further, the UE is configured to transmit a beam report skipping indication every two BR occasions. Thus, every other BR occasion is configured for communicating beam report skipping indications, as shown by the darkened pattern. The BRC is associated with a beam report periodicity 802. The beam report skipping indications may be transmitted with a beam report skipping periodicity 804 that is twice the periodicity 802. In other aspects, the periodicity 804 may be three times, four times, five times, or any other suitable multiple of the periodicity 802.

**[0101]** Referring to the scheme 850 of FIG. 8B, in other aspects, the UE or reporting device may be configured with different sets of resources for beam reporting and beam report skipping indications. The different sets of resources may be independent of one another, such that each set of resources is associated with its own periodicity and/or offset. In some aspects, one or more of the configured resources may overlap such that the resource may be configured for either or both of a beam report or a beam report skipping indication. For instance, in the scheme 850, the UE is configured with a BRC associated with a plurality of BR occasions. The plurality of BR occasions are associated with a beam reporting periodicity 808. Further, the UE is configured with beam report skipping indication resources associated with a beam report skipping periodicity 810 that is different from the periodicity 808. In general, the configured resources are configured or suitable for only those communications with which they are associated. Thus, the BR occasions are generally configured only for the communication of beam reports, and the BR skipping indication occasions are configured only for the communication of beam report skipping indications. However, in some aspects, one or more of the configured resources may overlap. For instance, FIG. 8B shows a slot 812 which is configured for both beam reports and beam report skipping indications. Thus, in the scheme 850, the periodicity and time offsets of the BR occasions and beam report skipping indication occasions are independent of one another.

**[0102]** FIG. 9 is a sequence diagram illustrating a communication method 900 that utilizes spatial-division multiplexed beams according to some aspects of the present disclosure. The method 900 may be performed by wireless networks, such as the networks 100 and/or 300 communicating over a high-frequency band, such as a mmWave band or a sub-THz band. In this regard, the method 900 is performed by a BS 105 and a UE 115. In some instances, the BS 105 may utilize TRPs (e.g., the TRPs 305) to communicate with the UE 115. For simplicity of illustration and discussion, the method 900 is discussed from the perspective of a single TRP co-located with the BS 105 or at a remote location from the BS 105. However, similar communications may also occur for other TRPs that are in communication with the BS 105. The method 900 may employ similar mechanisms as discussed above with reference to FIGS. 4-8B. In some aspects, the method 900 may be implemented after the BS 105 and the UE 115 establish a communication with each other. For example, the UE 115 may be in a connected mode (e.g., an RRC connected state). In some aspects, the BS 105 may utilize one or more components, such as the processor 1002, the memory 1004, the beam module 1008, the transceiver 1010, the modem 1012, and the one or more antennas 1016 shown in FIG. 10, to execute the actions of the method 900. The UE 115 may utilize one or more components, such as the processor 1102, the memory 1104, the beam module 1108, the transceiver 1110, the modem 1112, and the one or more antennas 1116 shown in FIG. 11, to execute the actions of the method 900. As illustrated, the method 900 includes a number of enumerated action, but embodiments of the method 900 may include additional actions before, after, and in between the enumerated actions. In some aspects, one or more of the enumerated actions may be omitted or performed in a different order. In FIG. 9, the arrows grouped by a dashed oval represent simultaneous transmissions.

**[0103]** At action 910, the BS 105 configures the UE 115 with one or more beam report configurations (BRCs). In some aspects, the BRCs are associated with a configuration for beam refinement. The configuration may indicate a plurality of resources (e.g., the CSI-RS resources) associated with a set of beam directions for beam sweeping. Each resource may be associated with one beam direction in the set of beam direction. The configuration can be a UE-specific configuration configured specifically for the UE 115. The one or more BRCs may include, or may be associated with, a set of resources for beam reports from the UE 115. For instance, a BRC may comprise a plurality of periodic beam reporting (BR) occasions in one or more CCs. In some aspects, the UE is configured with a plurality of BRCs in one or more CCs, as shown in FIG. 6B, for example. In some aspects, action 910 comprises the BS 105 configuring the UE 115 with a set of resources for beam report skipping indications in addition to beam reporting, as explained with respect to FIG. 8B, for instance. In another aspect, action 910 may comprise the BS 105 configuring the UE 115 with a configured timing offset for beam report skipping periods. In another aspect, the BS 105 may configure the UE 115 with one or more RRC tables, where each entry or row in the RRC table is associated with an index. Each entry or row, as indicated by the index, may correspond to one or more BRCs in one or more CCs. For instance, the UE may indicate that one or more BR occasions will be skipped by indicating one of the entries or rows in the RRC-configured table.

**[0104]** As part of beam refinement, the BS 105 may transmit a plurality of reference signals (e.g., CSI-RSs) by sweeping through the set of beam directions. At action 920, the BS 105 transmits a first reference signal of the plurality of reference signals in a first beam direction of a set of beam directions. In some aspects, action 920 comprises the BS 105 transmitting a CSI-RS. In another aspect, action 920 comprises the BS 105 transmitting a SSB. However, the BS 105 may transmit any suitable type of RS for beam management.

**[0105]** The BS 105 may continue through a beam sweep by transmitting N RSs to the UE 115 successively in N different beam directions, as shown in action 930. In action 940, the UE 115 performs beam measurements for the plurality of directional RSs transmitted at steps 920-930. In some aspects, action 930 comprises the UE 115 performing RSRP measurements. In other aspects, action 930 comprises the UE 115 performing RSRQ measurements, SNR measurements, and/or any other suitable type of measurement for beam management or refinement. The UE 115 may record the measurements such that they are associated with the corresponding beam direction.

**[0106]** In some aspects, a change in beam measurements may trigger the UE 115 to perform a beam management procedure that includes transmitting a beam report to the network via the BS 105. For instance, the UE 115 may communicate with the BS 105 via a serving beam direction. If the RSRP of the serving beam changes by a given amount, the UE 115 may be configured to transmit a beam report to the network. However, in some instances, the change in RSRP of the serving beam may not indicate that a different beam or beam direction would be preferrable or better than the current serving beam. For instance, the UE 115 may be moving toward or away from the BS 105. Accordingly, it may be desirable or beneficial for the UE 115 to skip one or more beam reporting occasions. By skipping the beam reporting, the UE 115 may conserve power and make more efficient use of network resources.

**[0107]** At action 950, the UE 115 determines to skip one or more BR occasions. In some aspects, action 950 comprises the UE 115 determining not to report or not to trigger a beam report based on one or more of a multi-beam metric, a ranking metric, or a combination thereof. For instance, in some aspects, the UE 115 may compare a first beam measurement (e.g., RSRP) associated with a serving beam direction to at least a second beam measurement associated with at least a second beam direction. If the first beam measurement is better than the at least the second beam measurement, the UE may determine not to trigger a beam report. In some aspects, based on a comparison of the different beam measurements, if the UE determines that the serving beam direction remains the top beam direction or is one of the top N beam directions (e.g., top two, top three, etc.), the UE 115 may determine not to trigger a beam report, and instead to transmit a beam report skipping indication.

**[0108]** In another example, the UE 115 may determine whether to trigger a beam report base don a ranking metric. For example, based on the beam measurements obtained at action 940, the UE 115 may determine an updated ranking for each of the plurality of beam directions. In some aspects, if the ranking of the beams remains unchanged, the UE 115 determines not to trigger a beam report. In another aspect, if the serving beam remains the top ranked beam, although there are other changes in the ranking, the UE 115 may determine not to trigger a beam report. In other aspects, the UE 115 may determine to trigger a beam report if there are any changes in the beam ranking since the last reporting.

**[0109]** At action 960, the UE 115 transmits one or more beam report skipping indications to the BS 105. In some aspects, the beam report skipping indication may apply to a single BRC in a single CC. In other aspects, the beam report skipping indication may apply to a plurality of BRCs in one or more CCs. In some aspects, the beam report skipping indication may implicitly indicate one or more beam reporting occasions to be skipped. In other aspects, the beam report skipping indication may indicate timing parameters associated with the one or more BR occasions to be skipped. For instance, as explained above with respect to FIGS. 6A-8B, the beam report skipping indication may indicate one or more of a length or a timing offset in slots, symbols, and/or BR occasions. In some aspects, the beam report skipping indication may indicate an index or value of a configured table associated with one or more BRCs, one or more CCs, one or more lengths of a beam report skipping period, one or more timing offsets for a beam report skipping period, a periodicity, and/or any other suitable set of parameters. Accordingly, the beam report skipping indication may incorporate any of the aspects explained above with respect to FIGS. 6A-8B.

**[0110]** FIG. 10 is a block diagram of an exemplary BS 1000 according to some aspects of the present disclosure. In some instances, the BS 1000 may be a BS 105 in the network 100 as discussed above in FIG. 1. In some other instances, the BS 1000 may be a TRP 305 in the network 300 as discussed above in FIG. 3. As explained above, a TRP may implement at least RF functionalities, but may also implement some baseband processing and/or protocol stack layer processing similar to a BS. As shown, the BS 1000 may include a processor 1002, a memory 1004, a beam module 1008, a transceiver 1010 including a modem subsystem 1012 and a RF unit 1014, and one or more antennas 1016. These elements may be coupled with one another. The term "coupled" may refer to directly or indirectly coupled or connected to one or more intervening elements. For instance, these elements may be in direct or indirect communication with each other, for example via one or more buses.

**[0111]** The processor 1002 may have various features as a specific-type processor. For example, these may include a CPU, a DSP, an ASIC, a controller, a FPGA device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein. The processor 1002 may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

**[0112]** The memory 1004 may include a cache memory (e.g., a cache memory of the processor 1002), RAM, MRAM, ROM, PROM, EPROM, EEPROM, flash memory, a solid state memory device, one or more hard disk drives, memristor-based arrays, other forms of volatile and non-volatile memory, or a combination of different types of memory. In some aspects, the memory 1004 may include a non-transitory computer-readable medium. The memory 1004 may store instructions 1006. The instructions 1006 may include instructions that, when executed by the processor 1002, cause the processor 1002 to perform operations described herein, for example, aspects of FIGS.

1-10. Instructions 1006 may also be referred to as program code. The program code may be for causing a wireless communication device to perform these operations, for example by causing one or more processors (such as processor 1002) to control or command the wireless communication device to do so. The terms “instructions” and “code” should be interpreted broadly to include any type of computer-readable statement(s). For example, the terms “instructions” and “code” may refer to one or more programs, routines, sub-routines, functions, procedures, etc. “Instructions” and “code” may include a single computer-readable statement or many computer-readable statements.

**[0113]** The beam module 1008 may be implemented via hardware, software, or combinations thereof. For example, the beam module 1008 may be implemented as a processor, circuit, and/or instructions 1006 stored in the memory 1004 and executed by the processor 1002. In some examples, the beam module 1008 can be integrated within the modem subsystem 1012. For example, the beam module 1008 can be implemented by a combination of software components (e.g., executed by a DSP or a general processor) and hardware components (e.g., logic gates and circuitry) within the modem subsystem 1012.

**[0114]** The beam module 1008 may communicate with various components of the BS 1000 to perform various aspects of the present disclosure, for example, aspects of FIGS. 1-9. In some aspects, the beam module 1008 is configured to transmit a plurality of reference signals in a set of beam directions to a UE (e.g., the UEs 115 and/or 1100). The reference signals may comprise CSI-RSs, SSBs, and/or any other suitable type of RS for beam management. The beam module 1008 is further configured to transmit the plurality of reference signals by transmitting, simultaneously during a first symbol, at least a first reference signal of the plurality of reference signals in a first beam direction of the set of beam directions and a second reference signal of the plurality of reference signals in a second beam direction of the set of beam directions, where the second beam direction is different from the first beam direction. In some aspects, the BS 1000 is communicatively coupled a first TRP and a second TRP, and the beam module 1008 is configured to transmit the first reference signal via the first TRP and transmit the second reference signal via the second TRP. The beam module 1008 is further configured receive a report indicating received signal measurements (e.g., L1-RSRPs) for two or more beam directions of the set of beam directions from the UE.

**[0115]** In some aspects, the beam module 1008 is configured to transmit, to the UE, one or more BRCs for beam reporting. In some aspects, the one or more BRCs may be associated with one or more CCs. In some aspects, the beam module 1008 is configured to transmit one or more RRC configurations for beam report skipping indications. For instance, the beam module 1008 may transmit, or output for transmission, one or more configurations for the UE to use in beam report skipping indications. The configurations may include a table of BRCs and associated CCs, for example. In some aspects, the one or more configurations may include or indicate one or more configured timing offset or beam report skipping length values.

**[0116]** In some aspects, the beam module 1008 is configured to receive one or more beam reports from one or more UEs based on a reference signal beam sweep. In another aspect, the beam module 1008 is configured to receive one or more beam report skipping indications from the UE.

**[0117]** As shown, the transceiver 1010 may include the modem subsystem 1012 and the RF unit 1014. The transceiver 1010 can be configured to communicate bi-directionally with other devices, such as the UEs 115 and/or another core network element. The modem subsystem 1012 may be configured to modulate and/or encode data according to a MCS, e.g., a LDPC coding scheme, a turbo coding scheme, a convolutional coding scheme, a digital beamforming scheme, etc. The RF unit 1014 may be configured to process (e.g., perform analog to digital conversion or digital to analog conversion, etc.) modulated/encoded data (e.g., RRC configuration, CSI-RS resource configuration, CSI-RS report configuration, CSI-RSs, SSB beams) from the modem subsystem 1012 (on outbound transmissions) or of transmissions originating from another source such as a UE 105. The RF unit 1014 may be further configured to perform analog beamforming in conjunction with the digital beamforming. Although shown as integrated together in transceiver 1010, the modem subsystem 1012 and/or the RF unit 1014 may be separate devices that are coupled together at the BS 105 to enable the BS 105 to communicate with other devices.

**[0118]** The RF unit 1014 may provide the modulated and/or processed data, e.g. data packets (or, more generally, data messages that may contain one or more data packets and other information), to the antennas 1016 for transmission to one or more other devices. The antennas 1016 may further receive data messages transmitted from other devices and provide the received data messages for processing and/or demodulation at the transceiver 1010. The transceiver 1010 may provide the demodulated and decoded data (e.g., UE capability report, beam reports) to the beam module 1008 for processing. The antennas 1016 may include multiple antennas of similar or different designs in order to sustain multiple transmission links. In some aspects, the antennas 1016 may in the form of one or more antenna panels or one or more antenna arrays each including a plurality of antenna element that can be selectively configured with different gains and/or phases to generate a beam for transmission and/or reception.

**[0119]** In some aspects, the transceiver 1010 is coupled to components of the BS 1000 and configured to transmit, to a UE, a plurality of reference signals in a set of beam directions (e.g., using transmission beams 310, 320, 620, 720, and/or 722). The transmitting the plurality of reference signals includes transmitting, simultaneously during a first symbol, at least a first reference signal of the plurality of reference signals in a first beam direction of the set of beam directions and a second reference signal of the plurality of reference signals in a second beam direction of the set of beam directions, where the second beam direction is different from the first beam direction. The transceiver 1010 is further configured to receive, from the UE, a report indicating received signal measurements (e.g., L1-RSRPs) for two or more beam directions of the set of beam direction.

**[0120]** In an aspect, the BS 1000 can include multiple transceivers 1010 implementing different RATs (e.g., NR and LTE). In an aspect, the BS 1000 can include a single transceiver 1010 implementing multiple RATs (e.g., NR and LTE). In an aspect, the transceiver 1010 can include various components, where different combinations of components can implement different RATs.

**[0121]** FIG. 11 is a block diagram of an exemplary UE 1100 according to some aspects of the present disclosure. In some instances, the UE 1100 may be a UE 115 as discussed above with respect to FIGS. 1 and 3. As shown, the UE 1100 may include a processor 1102, a memory 1104, a beam module 1108, a transceiver 1110 including a modem subsystem 1112 and a radio frequency (RF) unit 1114, and one or more antennas 1116. These elements may be coupled with one another. The term "coupled" may refer to directly or indirectly coupled or connected to one or more intervening elements. For instance, these elements may be in direct or indirect communication with each other, for example via one or more buses.

**[0122]** The processor 1102 may include a central processing unit (CPU), a digital signal processor (DSP), an application specific integrated circuit (ASIC), a controller, a field programmable gate array (FPGA) device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein. The processor 1102 may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

**[0123]** The memory 1104 may include a cache memory (e.g., a cache memory of the processor 1102), random access memory (RAM), magnetoresistive RAM (MRAM), read-only memory (ROM), programmable read-only memory (PROM), erasable programmable read only memory (EPROM), electrically erasable programmable read only memory (EEPROM), flash memory, solid state memory device, hard disk drives, other forms of volatile and non-volatile memory, or a combination of different types of memory. In an aspect, the memory 1104 includes a non-transitory computer-readable medium. The memory 1104 may store, or have recorded thereon, instructions 1106. The instructions 1106 may include instructions that, when executed by the processor 1102, cause the processor 1102 to perform the operations described herein with reference to the UEs 115 in connection with aspects of the present disclosure, for example, aspects of FIGS. 2-9. Instructions 1106 may also be referred to as program code, which may be interpreted broadly to include any type of computer-readable statement(s) as discussed above with respect to FIG. 10.

**[0124]** The beam module 1108 may be implemented via hardware, software, or combinations thereof. For example, the beam module 1108 may be implemented as a processor, circuit, and/or instructions 1106 stored in the memory 1104 and executed by the processor 1102. In some examples, the beam module 1108 can be integrated within the modem subsystem 1112. For example, the beam module 1108 can be implemented by a combination of software components (e.g., executed by a DSP or a general processor) and hardware components (e.g., logic gates and circuitry) within the modem subsystem 1112.

**[0125]** The beam module 1108 may communicate with various components of the UE 1100 to perform aspects of the present disclosure, for example, aspects of FIGS. 2-9. In some aspects, the beam module 1108 is configured to receive a plurality of reference signals (e.g., CSI-RSs, SSBs, etc.) in a set of beam directions from a BS (e.g., the BSs 105, 105, and/or 1000 and/or TRPs 305). The beam module 1108 is further configured to perform a plurality of RS measurements associated with each of the beam directions. In some aspects, the RS measurements comprise RSRP measurements. In other aspects, the RS measurements comprise RSRQ, SNR, and/or any other suitable type of RS measurement. In another aspect, the beam module 1108 is configured to transmit, based on the plurality of RS measurements, a first beam report skipping indication. In some aspects the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports. In some aspects, the first beam report skipping indication indicates the timing parameters or resources associated with the one or more beam reporting occasions to be skipped. In some aspects, the first beam report skipping indication indicates a length and/or a timing offset associated with the one or more skipped beam reporting occasions. In another aspect, the first beam report skipping indication indicates the one or more BRCs and/or CCs associated with the one or more skipped beam reporting occasions. It will be understood that the first beam report skipping indication may indicate any of the parameters described above with respect to FIGS. 6A-9.

**[0126]** As shown, the transceiver 1110 may include the modem subsystem 1112 and the RF unit 1114. The transceiver 1110 can be configured to communicate bi-directionally with other devices, such as the BSs 105. The modem subsystem 1112 may be configured to modulate and/or encode the data from the memory 1104 and/or the beam module 1108 according to a modulation and coding scheme (MCS), e.g., a low-density parity check (LDPC) coding scheme, a turbo coding scheme, a convolutional coding scheme, a digital beamforming scheme, etc. The RF unit 1114 may be configured to process (e.g., perform analog to digital conversion or digital to analog conversion, etc.) modulated/encoded data (e.g., UE capability report, beam reports) from the modem subsystem 1112 (on outbound transmissions) or of transmissions originating from another source such as a UE 115 or a BS 105. The RF unit 1114 may be further configured to perform analog beamforming in conjunction with the digital beamforming. Although shown as integrated together in transceiver 1110, the modem subsystem 1112 and the RF unit 1114 may be separate devices that are coupled together at the UE 115 to enable the UE 115 to communicate with other devices.

**[0127]** The RF unit 1114 may provide the modulated and/or processed data, e.g. data packets (or, more generally, data messages that may include one or more data packets and other information), to the antennas 1116 for transmission to one or more other devices. The antennas 1116 may further receive data messages transmitted from other devices. The antennas 1116 may provide the received data messages for processing and/or demodulation at the transceiver 1110. The transceiver 1110 may provide the demodulated and decoded data (e.g., RRC configuration, CSI-RS resource configuration, CSI-RS report configuration, CSI-RSs, SSB beams) to the beam module 1108 for processing. The antennas 1116 may include multiple antennas of similar or different designs in order to sustain multiple transmission links. The RF unit 1114 may configure the antennas 1116. In some aspects, the antennas 1116 may in the form of one or more antenna panels or one or more antenna arrays each including a plurality of antenna element that can be selectively configured with different gains and/or phases to generate a beam for transmission and/or reception.

**[0128]** In some aspects, the transceiver 1110 is coupled to components of the UE 1100 and configured to receive, from a BS, a plurality of reference signals in a set of beam directions (e.g., using transmission beams 310, 320, 620, 720, and/or 722). The receiving the plurality of reference signals includes transmitting, simultaneously during a first symbol, at least a first reference signal of the plurality of reference signals in a first beam direction of the set of beam directions and a second reference signal of the plurality of reference signals in a second beam direction of the set of beam directions, where the second beam direction is different from the first beam direction. The transceiver 1110 is further configured to transmit, to the UE, a report indicating received signal measurements (e.g., L1-RSRPs) for two or more beam directions of the set of beam direction.

**[0129]** In an aspect, the UE 1100 can include multiple transceivers 1110 implementing different RATs (e.g., NR and LTE). In an aspect, the UE 1100 can include a single transceiver 1110 implementing multiple RATs (e.g., NR and LTE). In an aspect, the transceiver 1110 can include various components, where different combinations of components can implement different RATs.

**[0130]** FIG. 12 is a flow diagram of a wireless communication method 1200 according to some aspects of the present disclosure. Aspects of the method 1200 can be executed by a computing device (e.g., a processor, processing circuit, and/or other suitable component) of a wireless communication device or other suitable means for performing the steps. For example, a wireless communication device, such as the UEs 115 and/or 1100 may utilize one or more components, such as the processor 1102, the memory 1104, the beam module 1208, the transceiver 1110, the modem 1112, and the one or more antennas 1116, to execute the steps of method 1200. The method 1200 may employ similar mechanisms as described above in FIGS. 6A-9. As illustrated, the method 1200 includes a number of enumerated steps, but aspects of the method 1200 may include additional steps before, after, and in between the enumerated steps. In some aspects, one or more of the enumerated steps may be omitted or performed in a different order.

**[0131]** At block 1210, a UE performs a plurality of reference signal measurements associated with a plurality of beam directions. In some aspects, block 1210 includes the UE receiving a plurality of reference signals associated with the plurality of beam directions. In some aspects, the reference signals comprise CSI-RSs. In other aspects, the plurality of reference signals comprise SSBs. However, any other suitable type of reference signal for beam management is also contemplated. In some aspects, performing the plurality of reference signal measurements comprises determining a RSRP value for each of the plurality of beam directions based on the detected reference signals. In other aspects, performing the plurality of reference signal measurements comprises determining a RSRP, SNR, and/or any other suitable type of signal measurement associated with the plurality of reference signals.

**[0132]** At block 1220, the UE transmits, based on the reference signal measurements, a first beam report skipping indication. The first beam report skipping indication may indicate one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports. In some aspects, transmitting the first beam report indication comprises transmitting UCI in a beam reporting occasion based on a beam report configuration (BRC). In some aspects, the UCI indicates one or more of a length or a timing offset associated with a beam report skipping period. In some aspects, the first beam report indication indicates one or more BRC IDs and/or one or more CC indices. For instance, the first beam report skipping indication may indicate a single BRC in a single CC, or a plurality of BRCs in one or more CCs. In some aspects, the first beam report skipping indication indicates one or more indices associated with a RRC configuration. In some aspects, the one or more parameters associated with the beam report skipping period may be indicated by a number of slots, a number of symbols, a number of subframes, a number of mini-slots, a number of beam reporting occasions, and/or any other suitable time unit.

**[0133]** In some aspects, block 1220 comprises transmitting the first beam report skipping indication in a beam reporting occasion configured for communicating beam repots. In another aspect, block

1220 comprises transmitting the first beam report skipping indication in a beam report skipping indication resource configured for communicating beam report skipping indications but not for beam reports. In some aspects, block 1220 comprises transmitting the first beam report skipping indication in a resource configured for communicating either or both of beam reports and beam report skipping indications.

**[0134]** In some aspects, the method 1200 comprises the UE determining, based on the plurality of reference signal measurements, to refrain from transmitting the one or more beam reports based on a comparison reference signal measurements. For example, the UE may compare a first RSRP measurement associated with a serving beam direction to at least a second RSRP measurement associated with at least one other beam direction. In another aspect, determining to refrain from transmitting the one or more beam reports is based on a determination of a change in beam rank among the plurality of beam directions, as explained above.

## EXEMPLARY ASPECTS OF THE DISCLOSURE

**[0135]** In addition to the disclosure above, the present disclosure contemplates the following aspects:

**[0136]** Aspect 1. A method of wireless communication by a user equipment (UE), the method comprising: performing a plurality of reference signal measurements associated with a plurality of beam directions; and transmitting, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

**[0137]** Aspect 2. The method of aspect 1, wherein the performing the plurality of reference signal measurements comprising performing a plurality of reference signal received power (RSRP) measurements.

**[0138]** Aspect 3. The method of aspect 2, wherein the performing the plurality of RSRP measurements comprises performing the plurality of RSRP measurements for one of: a plurality of channel state information reference signals (CSI-RSs) associated with the plurality of beam directions; or a plurality of synchronization signal blocks (SSBs) associated with the plurality of beam directions.

**[0139]** Aspect 4. The method of any of aspects 1-3, wherein the transmitting the beam report skipping indication comprises transmitting uplink control information (UCI), wherein the beam report skipping indication indicates one or more beam report configurations associated with the one or more beam reporting occasions.

**[0140]** Aspect 5. The method of aspect 4, wherein the beam report skipping indication indicates a single beam report configuration and a single component carrier associated with the one or more beam reporting occasions.

**[0141]** Aspect 6. The method of aspect 5, wherein the UCI indicates a plurality of beam report configuration identifiers associated with the plurality of beam report configurations.

**[0142]** Aspect 7. The method of aspect 5, wherein the UCI indicates an index associated with a radio resource control (RRC) configuration, wherein the index is associated with the single beam report configuration and a single component carrier (CC).

**[0143]** Aspect 8. The method of aspect 4, wherein the beam report skipping indication indicates a plurality of beam report configuration associated with the one or more beam reporting occasions.

**[0144]** Aspect 9. The method of aspect 8, wherein the plurality of beam report configurations are associated with a plurality of component carriers (CCs).

**[0145]** Aspect 10. The method of aspect 8, wherein the plurality of beam report configurations are associated with a single component carrier (CC).

**[0146]** Aspect 11. The method of any of aspects 8-10, wherein the UCI indicates a plurality of beam report configuration identifiers associated with the plurality of beam report configurations.

**[0147]** Aspect 12. The method of any of aspects 8-11, wherein the UCI indicates an index associated with a radio resource control (RRC) configuration, wherein the index is associated with the plurality of beam report configurations.

**[0148]** Aspect 13. The method of any of aspects 1-12, wherein the beam report skipping indication indicates one or more time resources associated with the one or more beam reporting occasions.

**[0149]** Aspect 14. The method of aspect 13, wherein the beam report skipping indication indicates a length of time during which the UE will refrain from transmitting the one or more beam reports.

**[0150]** Aspect 15. The method of aspect 14, wherein the beam report skipping indication further indicates a time offset preceding the length of time during which the UE will refrain from transmitting the one or more beam reports.

**[0151]** Aspect 16. The method of aspect 14, wherein the length of time follows a configured offset period.

**[0152]** Aspect 17. The method of aspect 16, wherein the configured offset period comprises a number of slots or a number of symbols.

**[0153]** Aspect 18. The method of aspect 16, wherein the configured offset period comprises a number of beam reporting occasions.

**[0154]** Aspect 19. The method of aspect 13, wherein the beam report skipping indication indicates the one or more time resources associated with the one or more beam reporting occasions in terms of at least one of a number of slots or a number of symbols.

**[0155]** Aspect 20. The method of aspect 13, wherein the beam report skipping indication indicates the one or more time resources associated with the one or more beam reporting occasions in terms of at least one of a number of beam reporting occasions or one or more beam reporting periodicities.

**[0156]** Aspect 21. The method of any of aspects 1-20, further comprising: receiving, from a network entity: a first beam report configuration associated with a first periodicity and a first time offset; and a second beam report configuration associated with a second periodicity and a second time offset, wherein the first beam report configuration is configured for receiving beam reports and beam report skipping indications, and wherein the second beam report configuration is configured for receiving beam reports and is not configured for receiving beam report skipping indications.

**[0157]** Aspect 22. The method of aspect 21, wherein the transmitting the first beam report skipping indication comprises transmitting the first beam report skipping indication in a first beam reporting occasion associated with the first beam report configuration.

**[0158]** Aspect 23. The method of any of aspects 21-22, further comprising: receiving, from the network entity, a beam report skipping configuration associated with a third periodicity and a third time offset, wherein the transmitting the first beam report skipping indication comprises transmitting the first beam report skipping indication in a first beam report skipping occasion associated with the beam report skipping configuration.

**[0159]** Aspect 24. The method of any of aspects 1-23, wherein: the plurality of reference signal measurements comprises a first reference signal measurement associated with a first beam direction and a second reference signal measurement associated with a second beam direction; the first beam direction is associated with a serving beam; and the transmitting the first beam report skipping indication is based on a comparison of the first reference signal measurement to the second reference signal measurement.

**[0160]** Aspect 25. The method of any of aspects 1-24, wherein the transmitting the first beam report skipping indication is based on a channel ranking of the plurality of beam directions, and wherein the channel ranking is based on the plurality of reference signal measurements.

**[0161]** Aspect 26. A user equipment (UE), comprising: a memory device; a transceiver; and a processor in communication with the memory device and the transceiver, wherein the UE is configured to perform the actions of any of aspects 1-25.

**[0162]** Aspect 27. A non-transitory, computer-readable memory having program code recorded thereon, wherein the program code is executable by a processor of a user equipment (UE) to cause the UE to perform the actions of any of aspects 1-25.

**[0163]** Aspect 28. A user equipment (UE) comprising means for performing the actions of any of aspects 1-25.

**[0164]** Information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

**[0165]** The various illustrative blocks and modules described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a DSP, an ASIC, an FPGA or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (*e.g.*, a combination of a DSP and a microprocessor, multiple microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

**[0166]** The functions described herein may be implemented in hardware, software executed by a processor, firmware, or any combination thereof. If implemented in software executed by a processor, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Other examples and implementations are within the scope of the disclosure and appended claims. For example, due to the nature of software, functions described above can be implemented using software executed by a processor, hardware, firmware, hardwiring, or combinations of any of these. Features implementing functions may also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations. Also, as used herein, including in the claims, "or" as used in a list of items (for example, a list of items prefaced by a phrase such as "at least one of" or "one or more of") indicates an inclusive list such that, for example, a list of [at least one of A, B, or C] means A or B or C or AB or AC or BC or ABC (i.e., A and B and C).

**[0167]** As those of some skill in this art will by now appreciate and depending on the particular application at hand, many modifications, substitutions and variations can be made in and to the materials, apparatus, configurations and methods of use of the devices of the present disclosure without departing from the spirit and scope thereof. In light of this, the scope of the present disclosure should not be limited to that of the particular embodiments illustrated and described herein, as they are merely by way of some examples thereof, but rather, should be fully commensurate with that of the claims appended hereafter and their functional equivalents.

**WHAT IS CLAIMED IS:**

1. A method of wireless communication by a user equipment (UE), the method comprising:

performing a plurality of reference signal measurements associated with a plurality of beam directions; and

transmitting, based on the reference signal measurements, a first beam report skipping indication, wherein the beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

2. The method of claim 1, wherein the performing the plurality of reference signal measurements comprising performing a plurality of reference signal received power (RSRP) measurements.

3. The method of claim 2, wherein the performing the plurality of RSRP measurements comprises performing the plurality of RSRP measurements for one of:

a plurality of channel state information reference signals (CSI-RSs) associated with the plurality of beam directions; or

a plurality of synchronization signal blocks (SSBs) associated with the plurality of beam directions.

4. The method of claim 1, wherein the transmitting the beam report skipping indication comprises transmitting uplink control information (UCI), wherein the beam report skipping indication indicates one or more beam report configurations associated with the one or more beam reporting occasions.

5. The method of claim 4, wherein the beam report skipping indication indicates a single beam report configuration and a single component carrier associated with the one or more beam reporting occasions.

6. The method of claim 5, wherein the UCI indicates a plurality of beam report configuration identifiers associated with the plurality of beam report configurations.

7. The method of claim 5, wherein the UCI indicates an index associated with a radio resource control (RRC) configuration, wherein the index is associated with the single beam report

configuration and a single component carrier (CC).

8. The method of claim 4, wherein the beam report skipping indication indicates a plurality of beam report configuration associated with the one or more beam reporting occasions.

9. The method of claim 8, wherein the plurality of beam report configurations are associated with a plurality of component carriers (CCs).

10. The method of claim 8, wherein the plurality of beam report configurations are associated with a single component carrier (CC).

11. The method of claim 8, wherein the UCI indicates a plurality of beam report configuration identifiers associated with the plurality of beam report configurations.

12. The method of claim 8, wherein the UCI indicates an index associated with a radio resource control (RRC) configuration, wherein the index is associated with the plurality of beam report configurations.

13. The method of claim 1, wherein the beam report skipping indication indicates one or more time resources associated with the one or more beam reporting occasions.

14. The method of claim 13, wherein the beam report skipping indication indicates a length of time during which the UE will refrain from transmitting the one or more beam reports.

15. The method of claim 14, wherein the beam report skipping indication further indicates a time offset preceding the length of time during which the UE will refrain from transmitting the one or more beam reports.

16. The method of claim 14, wherein the length of time follows a configured offset period.

17. The method of claim 16, wherein the configured offset period comprises a number of slots or a number of symbols.

18. The method of claim 16, wherein the configured offset period comprises a number of beam

reporting occasions.

19. The method of claim 13, wherein the beam report skipping indication indicates the one or more time resources associated with the one or more beam reporting occasions in terms of at least one of a number of slots or a number of symbols.

20. The method of claim 13, wherein the beam report skipping indication indicates the one or more time resources associated with the one or more beam reporting occasions in terms of at least one of a number of beam reporting occasions or one or more beam reporting periodicities.

21. The method of claim 1, further comprising:

receiving, from a network entity:

a first beam report configuration associated with a first periodicity and a first time offset; and

a second beam report configuration associated with a second periodicity and a second time offset, wherein the first beam report configuration is configured for receiving beam reports and beam report skipping indications, and wherein the second beam report configuration is configured for receiving beam reports and is not configured for receiving beam report skipping indications.

22. The method of claim 21, wherein the transmitting the first beam report skipping indication comprises transmitting the first beam report skipping indication in a first beam reporting occasion associated with the first beam report configuration.

23. The method of claim 21, further comprising:

receiving, from the network entity, a beam report skipping configuration associated with a third periodicity and a third time offset,

wherein the transmitting the first beam report skipping indication comprises transmitting the first beam report skipping indication in a first beam report skipping occasion associated with the beam report skipping configuration.

24. The method of claim 1, wherein:

the plurality of reference signal measurements comprises a first reference signal measurement associated with a first beam direction and a second reference signal measurement associated with a second beam direction;

the first beam direction is associated with a serving beam; and

the transmitting the first beam report skipping indication is based on a comparison of the first reference signal measurement to the second reference signal measurement.

25. The method of claim 1, wherein the transmitting the first beam report skipping indication is based on a channel ranking of the plurality of beam directions, and wherein the channel ranking is based on the plurality of reference signal measurements.

26. A user equipment (UE), comprising:

a memory device;

a transceiver; and

a processor in communication with the memory device and the transceiver, wherein the UE is configured to:

perform a plurality of reference signal measurements associated with a plurality of beam directions; and

transmit, based on the reference signal measurements, a beam report skipping indication, wherein beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

27. The UE of claim 26, wherein the beam report skipping indication indicates one or more beam report configurations associated with the one or more beam reporting occasions.

28. The UE of claim 26, wherein the beam report skipping indication indicates one or more slots or one or more symbols during which the UE will refrain from transmitting the one or more beam reports.

29. A non-transitory, computer-readable memory having program code recorded thereon, wherein the program code is executable by a processor of a user equipment (UE) to cause the UE to:

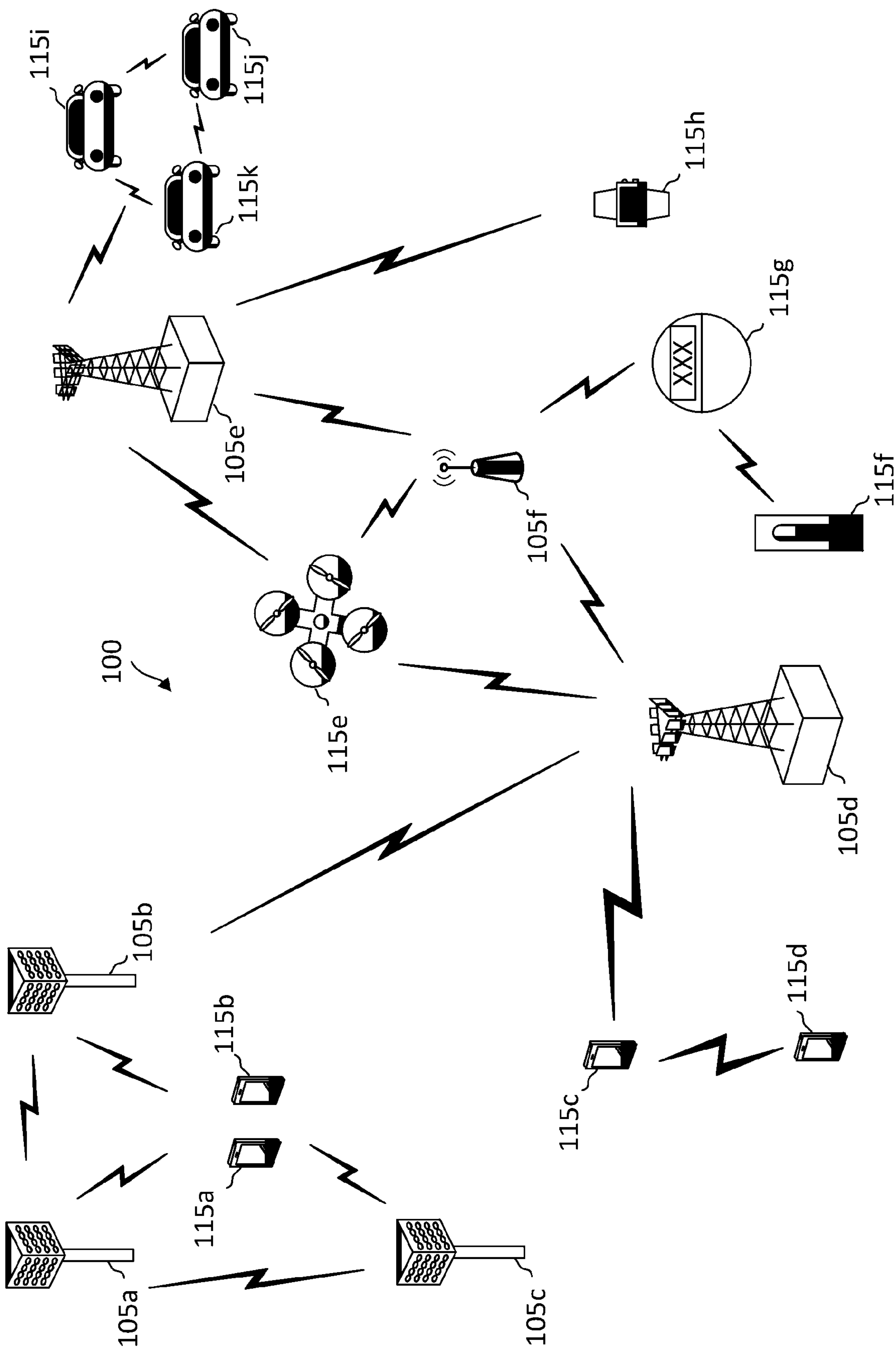
perform a plurality of reference signal measurements associated with a plurality of beam directions; and

transmit, based on the reference signal measurements, a beam report skipping indication, wherein beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.

30. A user equipment (UE) comprising:

means for performing a plurality of reference signal measurements associated with a plurality of beam directions; and

means for transmitting, based on the reference signal measurements, a beam report skipping indication, wherein beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports.


100
105a
105b
105c
105d
105e
105f
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115b
115c
115d
115e
115f
115g
115h
115i
115j
115k
XXX

FIG. 1

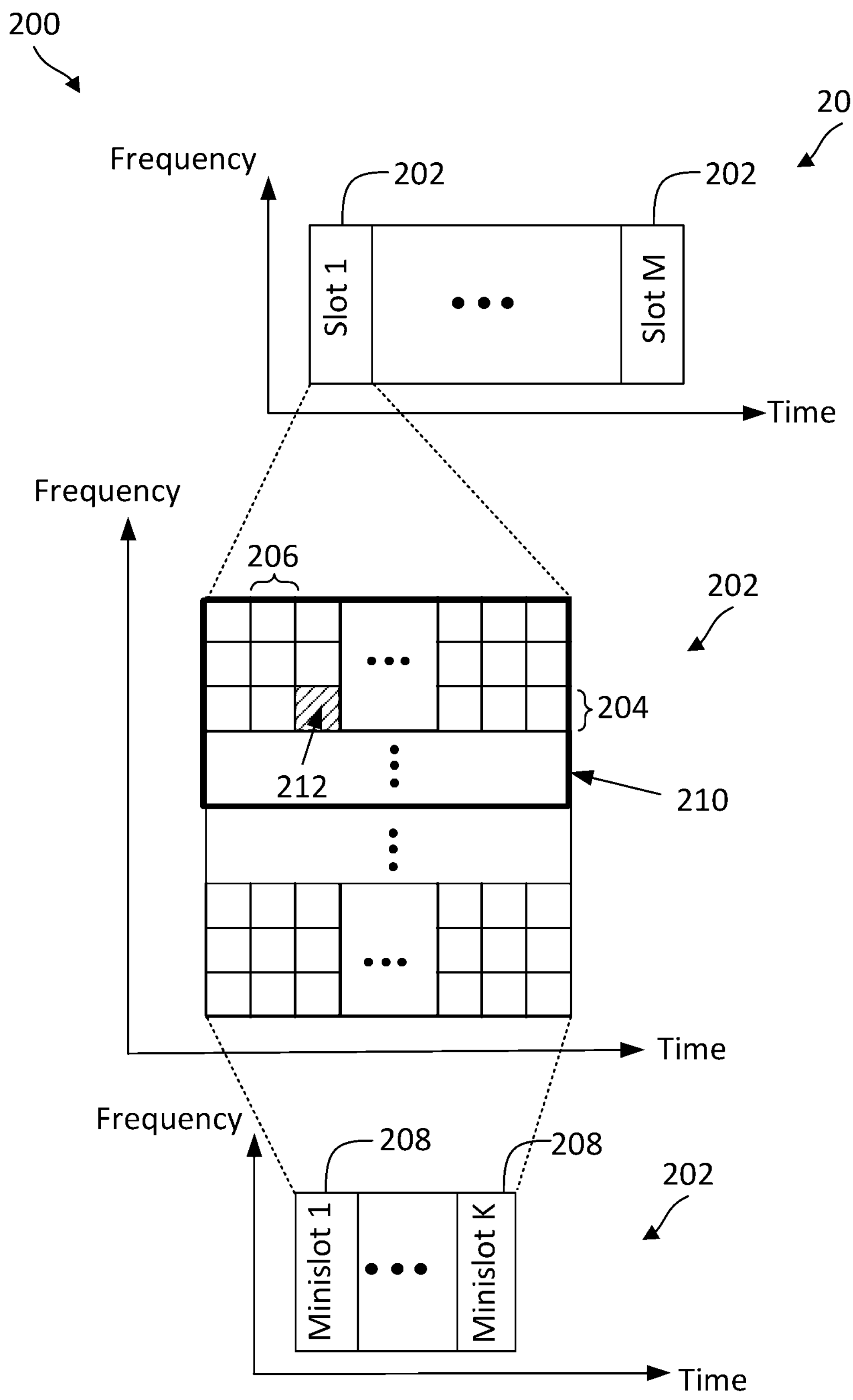
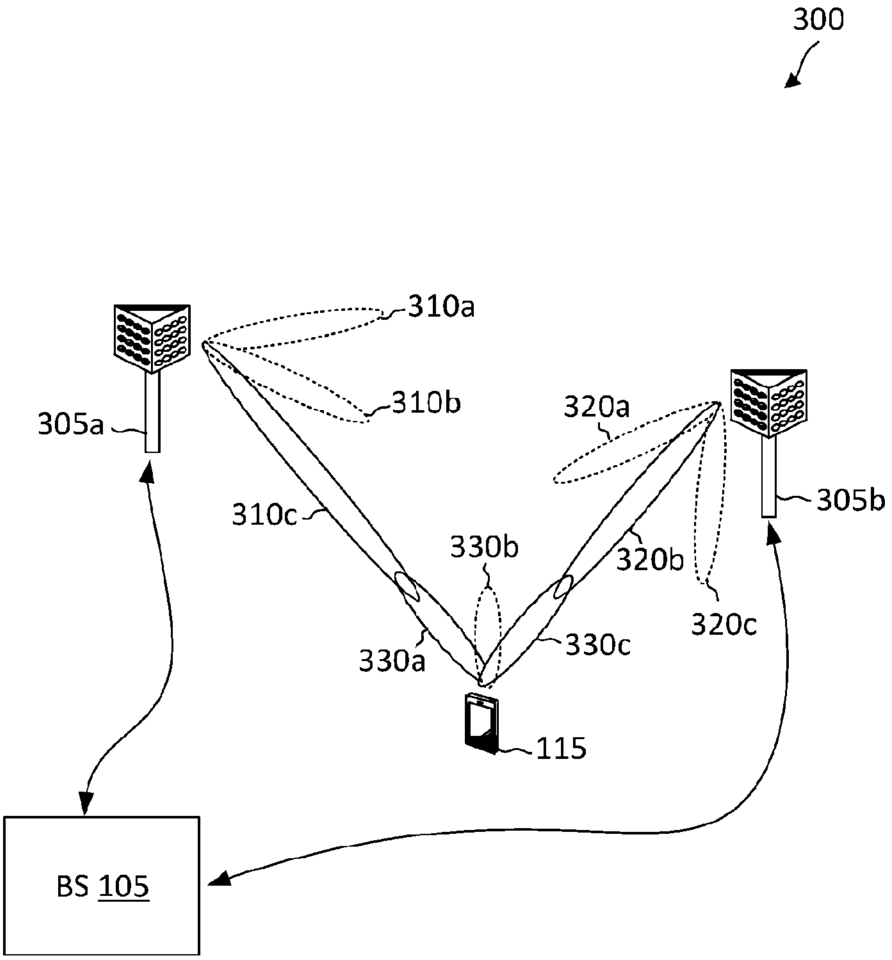

200
201
Frequency
202
202
Slot 1
Slot M
Time
Frequency
206
202
204
212
210
Time
Frequency
208
208
202
Minislot 1
Minislot K
Time

FIG. 2


300
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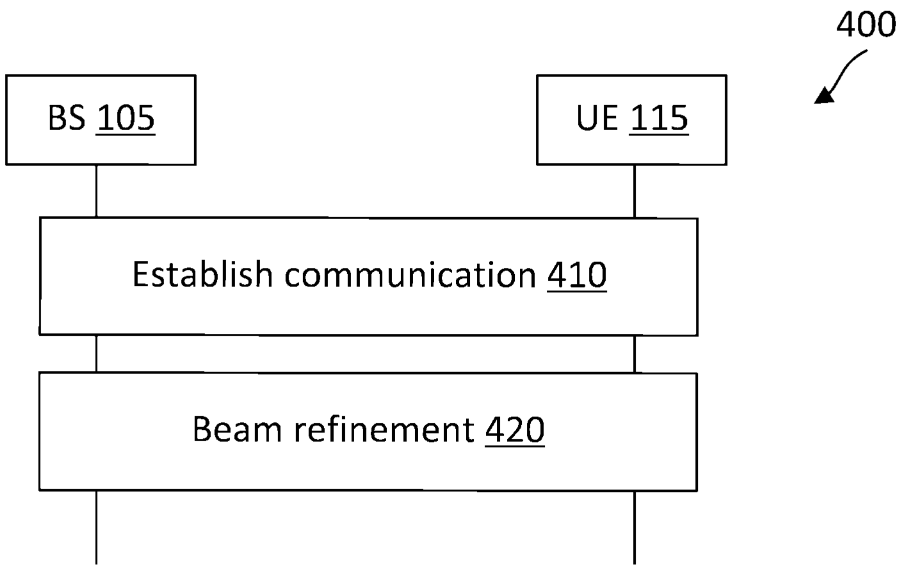
310b
305a
320a
310c
305b
330b
320b
320c
330a
330c
115
BS 105

FIG. 3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BS 105
UE 115
Establish communication 410
Beam refinement 420

FIG. 4

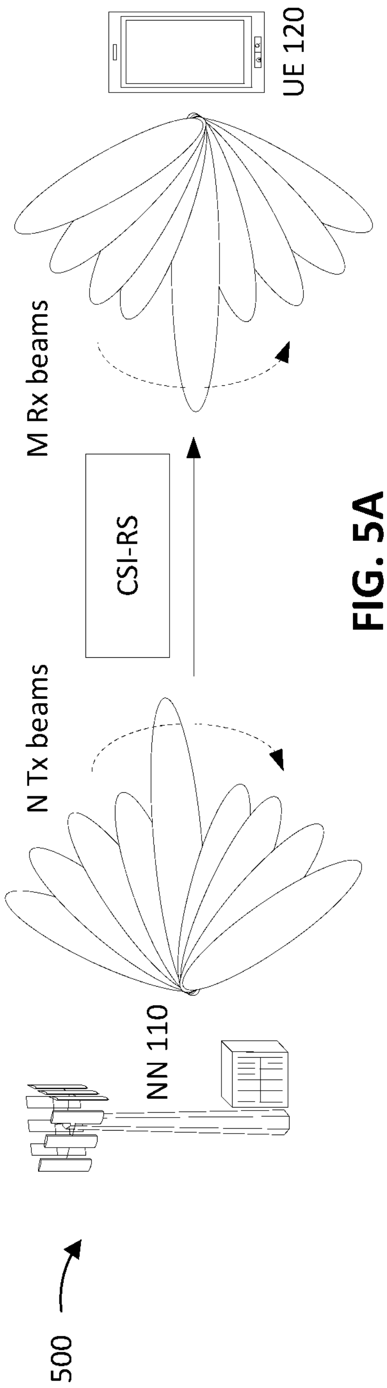


FIG. 5A

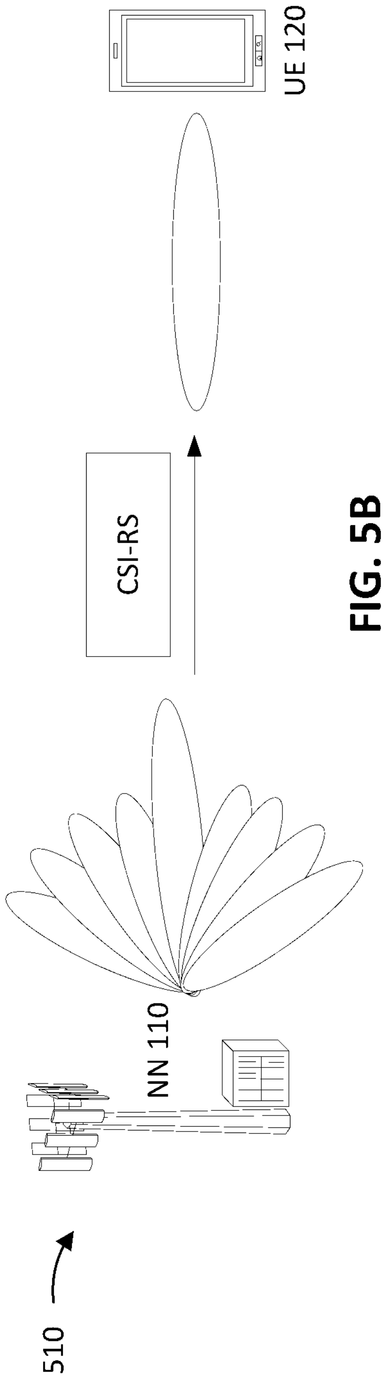


FIG. 5B

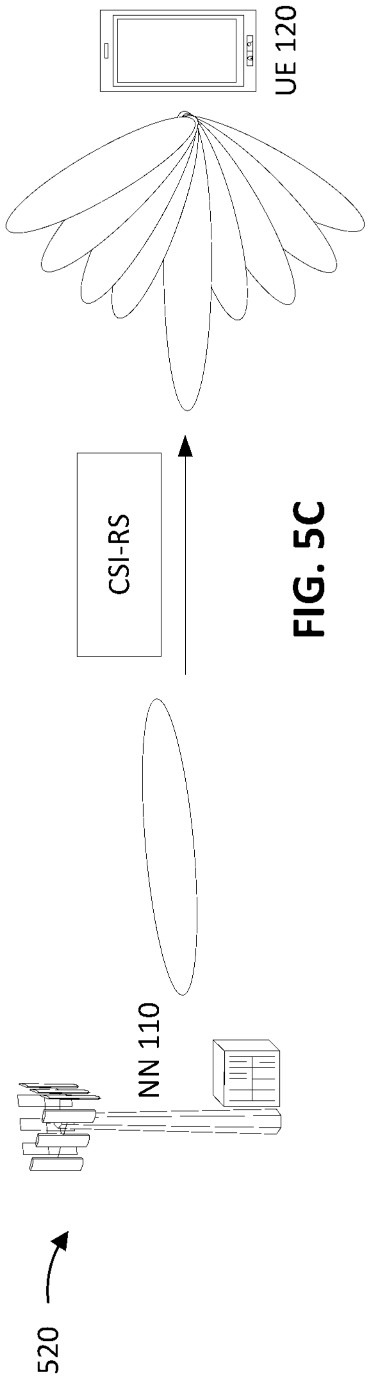


FIG. 5C

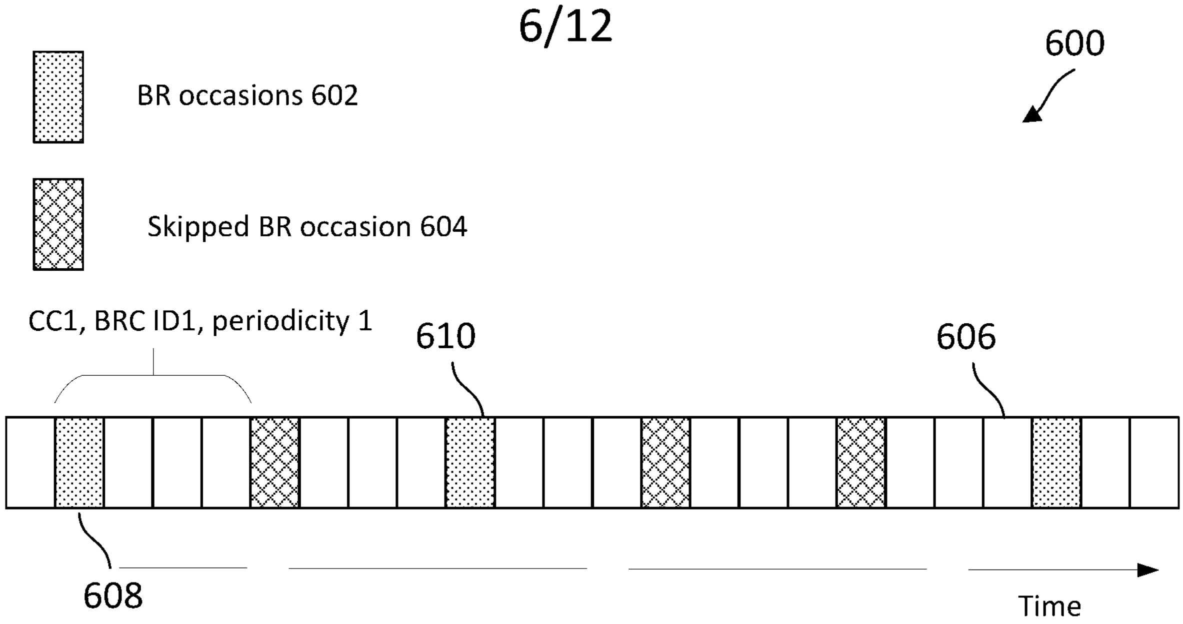
600
BR occasions 602
Skipped BR occasion 604
CC1, BRC ID1, periodicity 1
610
606
608
Time

FIG. 6A

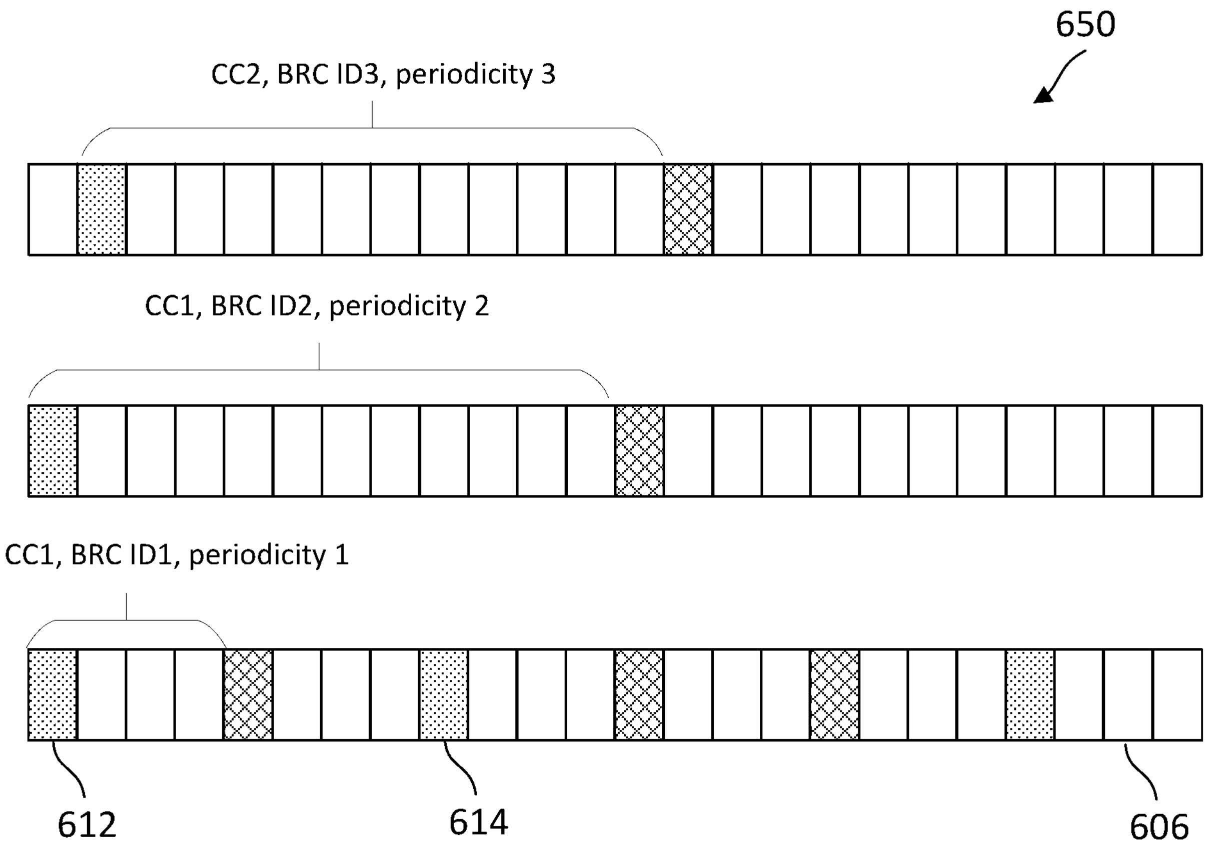
650
CC2, BRC ID3, periodicity 3
CC1, BRC ID2, periodicity 2
CC1, BRC ID1, periodicity 1
612
614
606

FIG. 6B

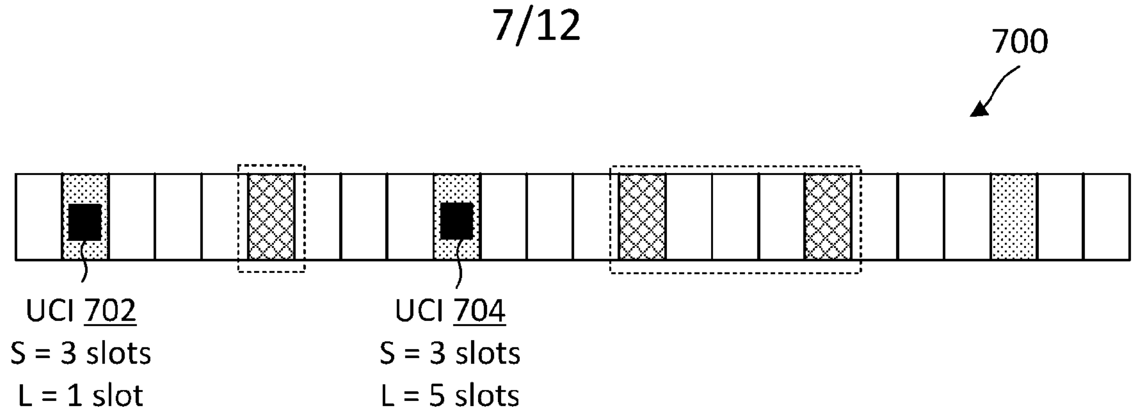


FIG. 7A

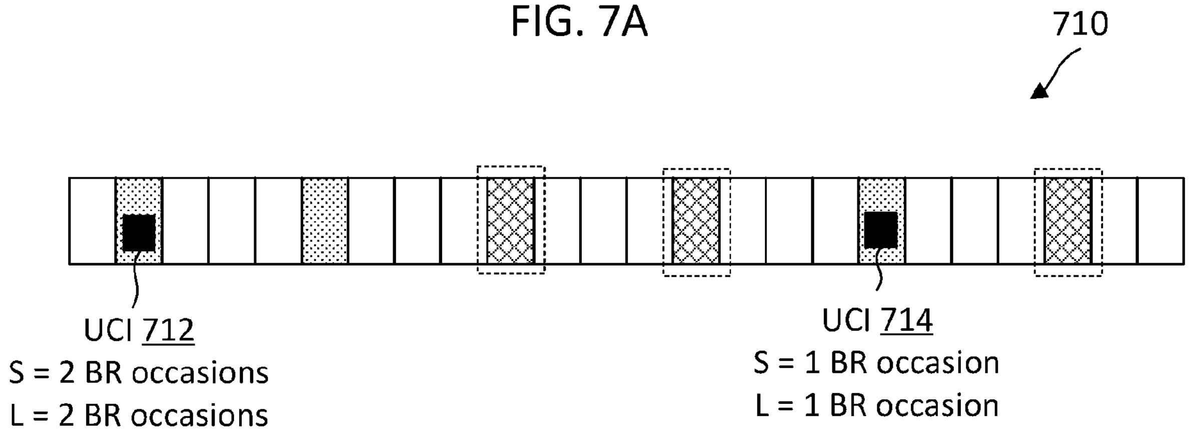


FIG. 7B

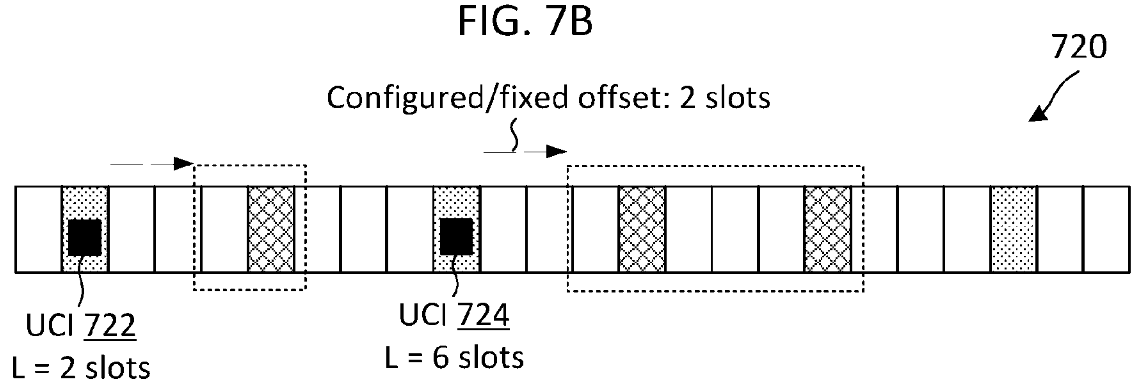


FIG. 7C

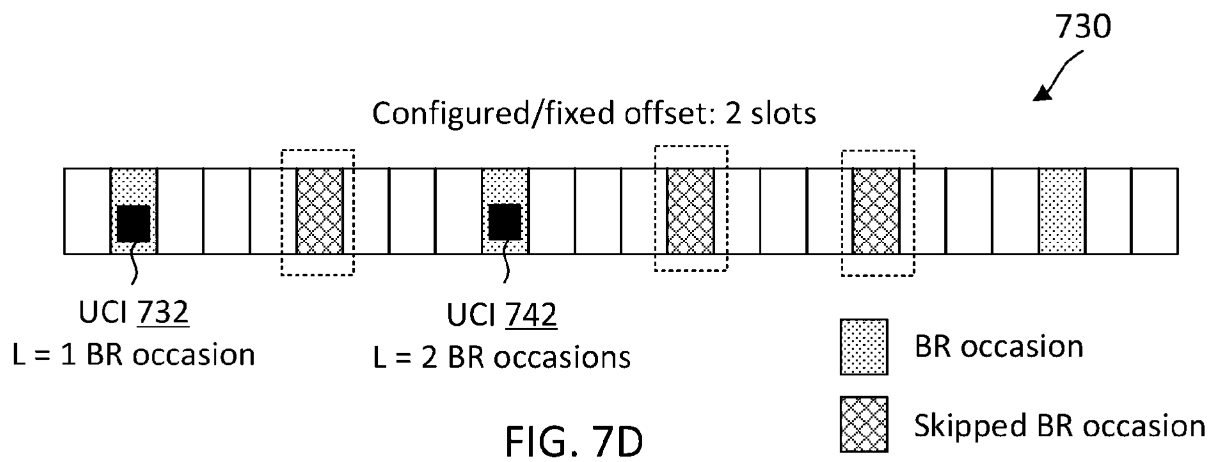


FIG. 7D

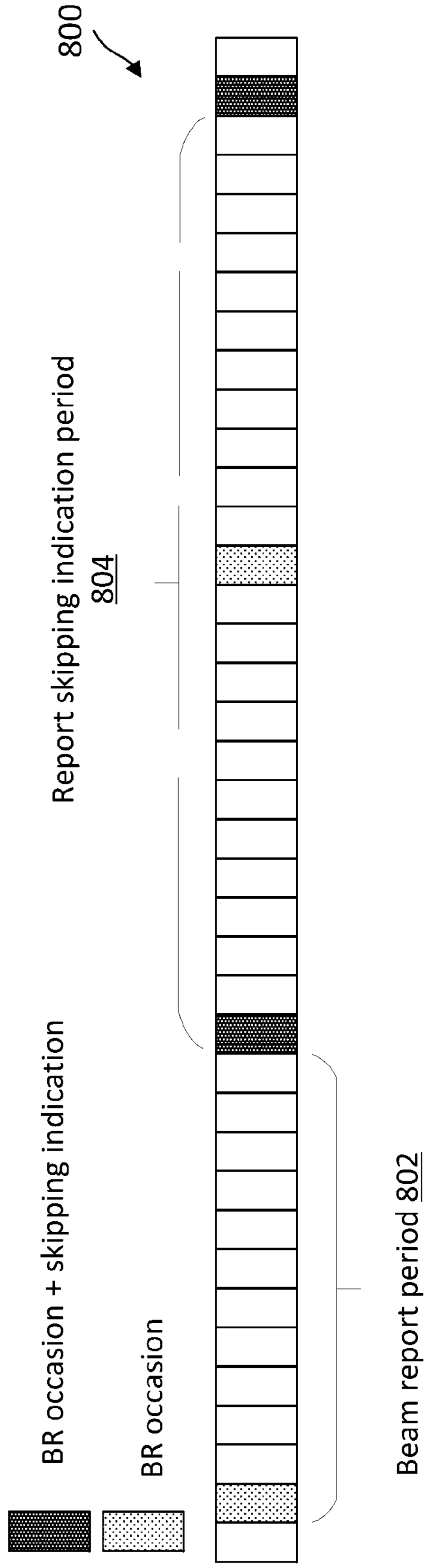
800
Report skipping indication period 804
Beam report period 802
BR occasion + skipping indication
BR occasion

FIG. 8A

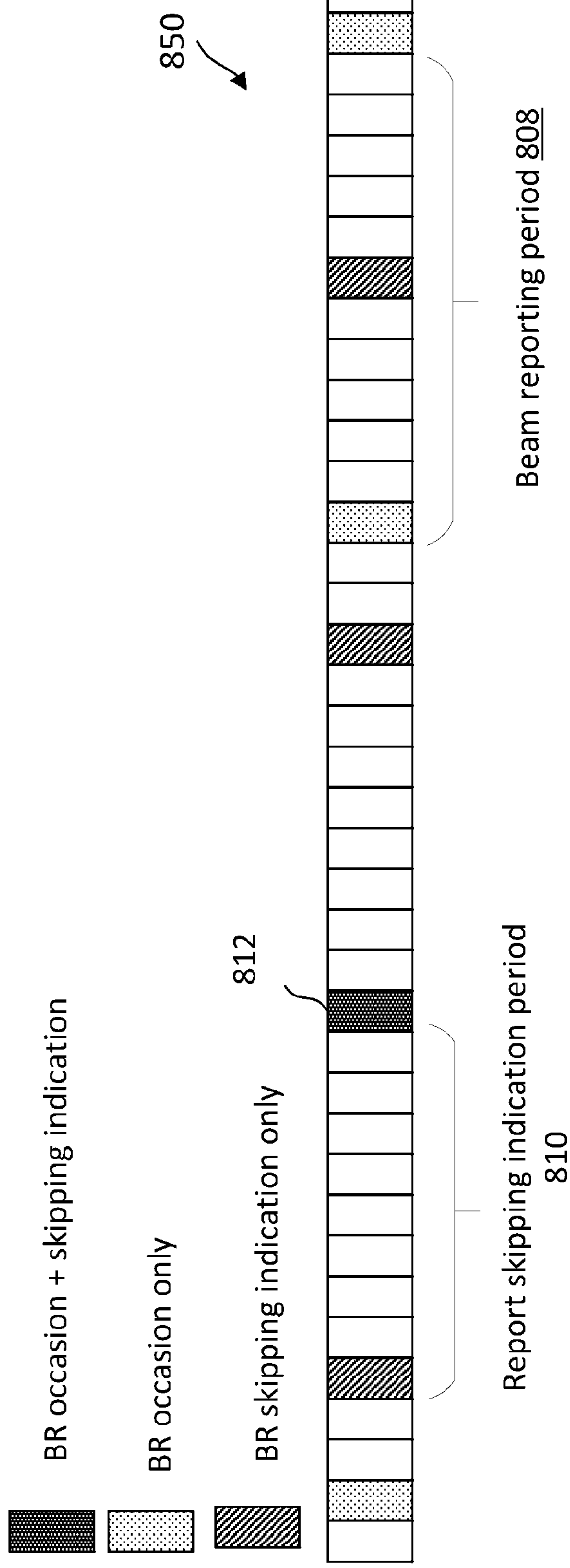
850
Beam reporting period 808
812
Report skipping indication period 810
BR occasion + skipping indication
BR occasion only
BR skipping indication only

FIG. 8B

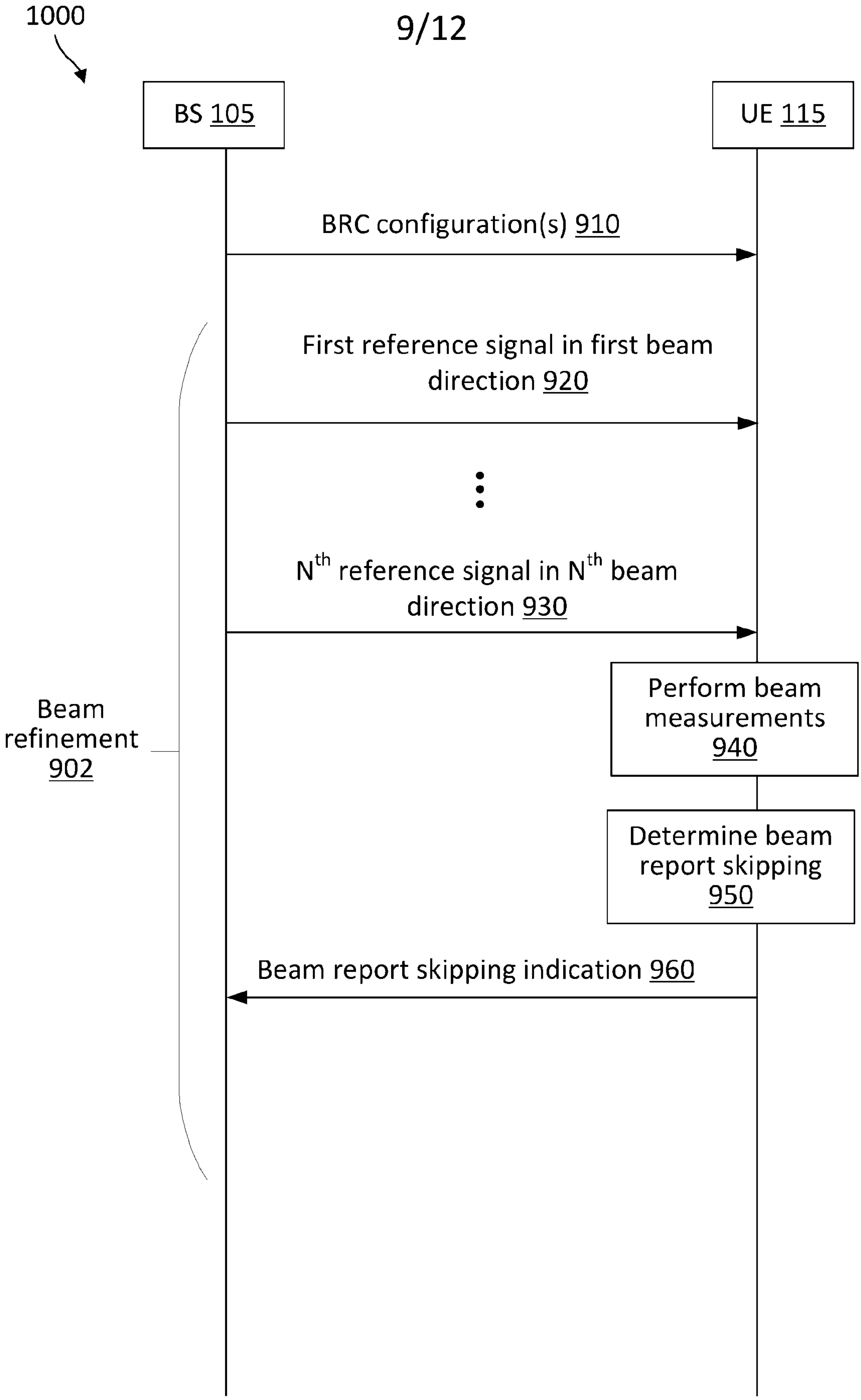
1000
BS 105
UE 115
BRC configuration(s) 910
First reference signal in first beam direction 920
Nth reference signal in Nth beam direction 930
Perform beam measurements 940
Determine beam report skipping 950
Beam report skipping indication 960
Beam refinement 902

FIG. 9

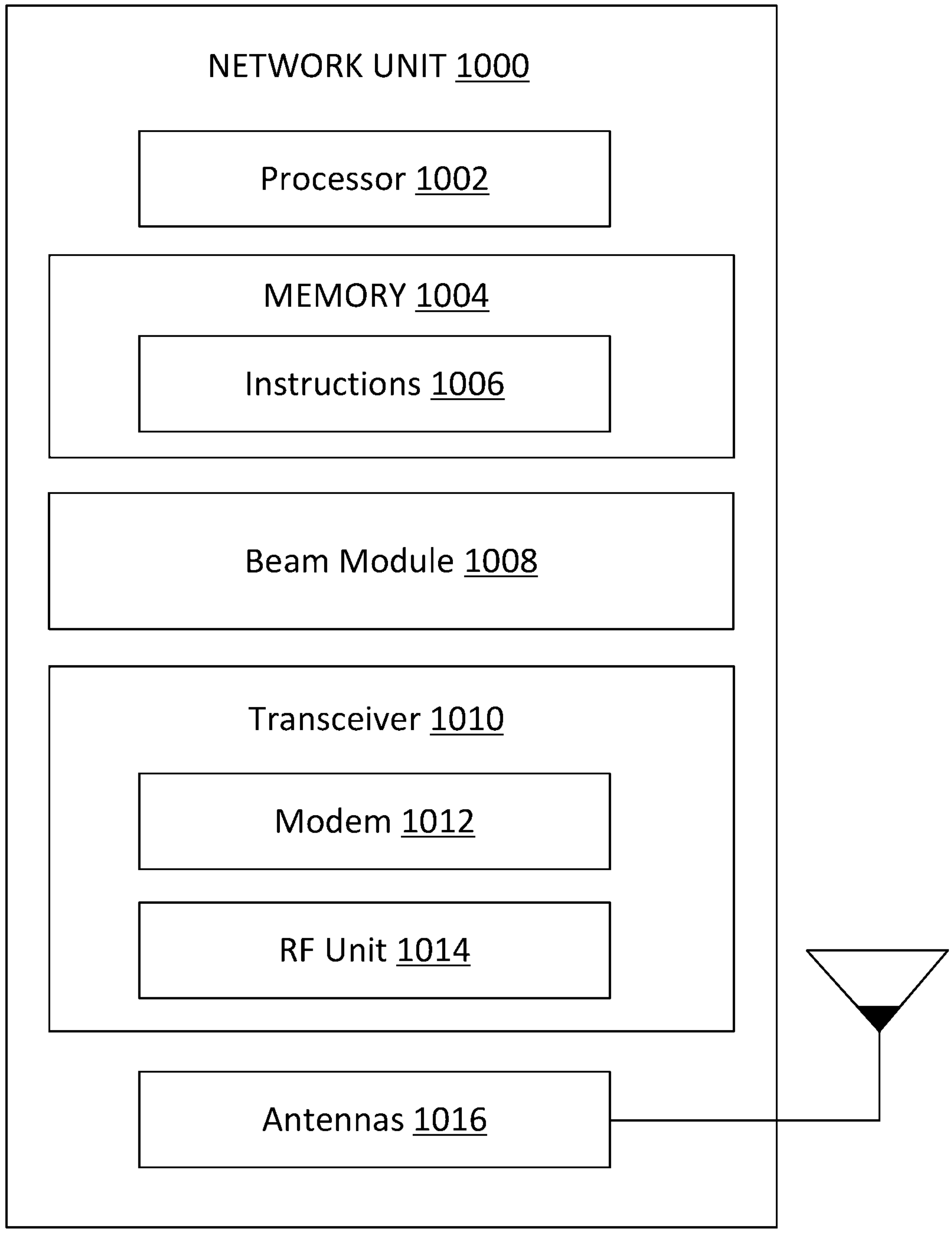
NETWORK UNIT 1000
Processor 1002
MEMORY 1004
Instructions 1006
Beam Module 1008
Transceiver 1010
Modem 1012
RF Unit 1014
Antennas 1016

FIG. 10

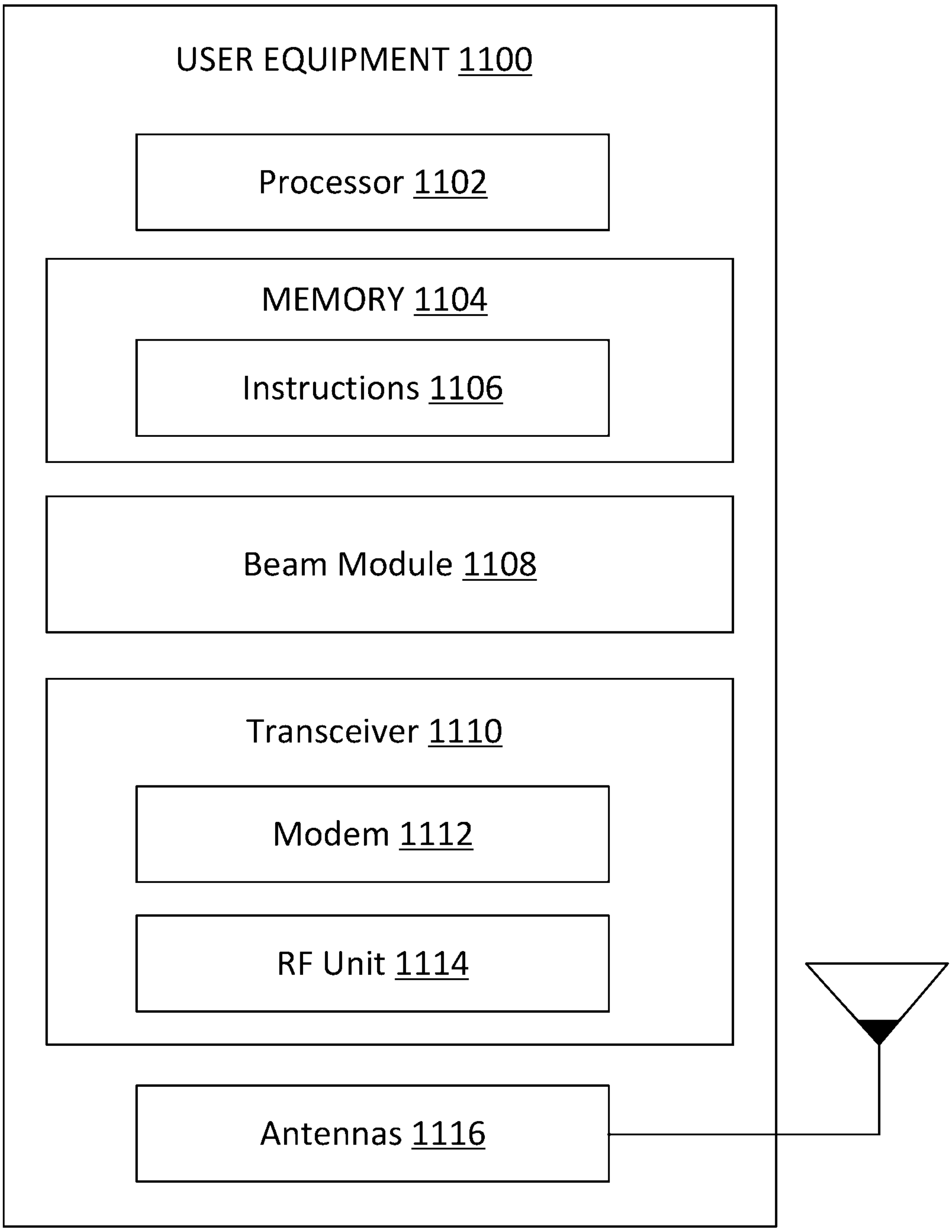
USER EQUIPMENT 1100
Processor 1102
MEMORY 1104
Instructions 1106
Beam Module 1108
Transceiver 1110
Modem 1112
RF Unit 1114
Antennas 1116

FIG. 11

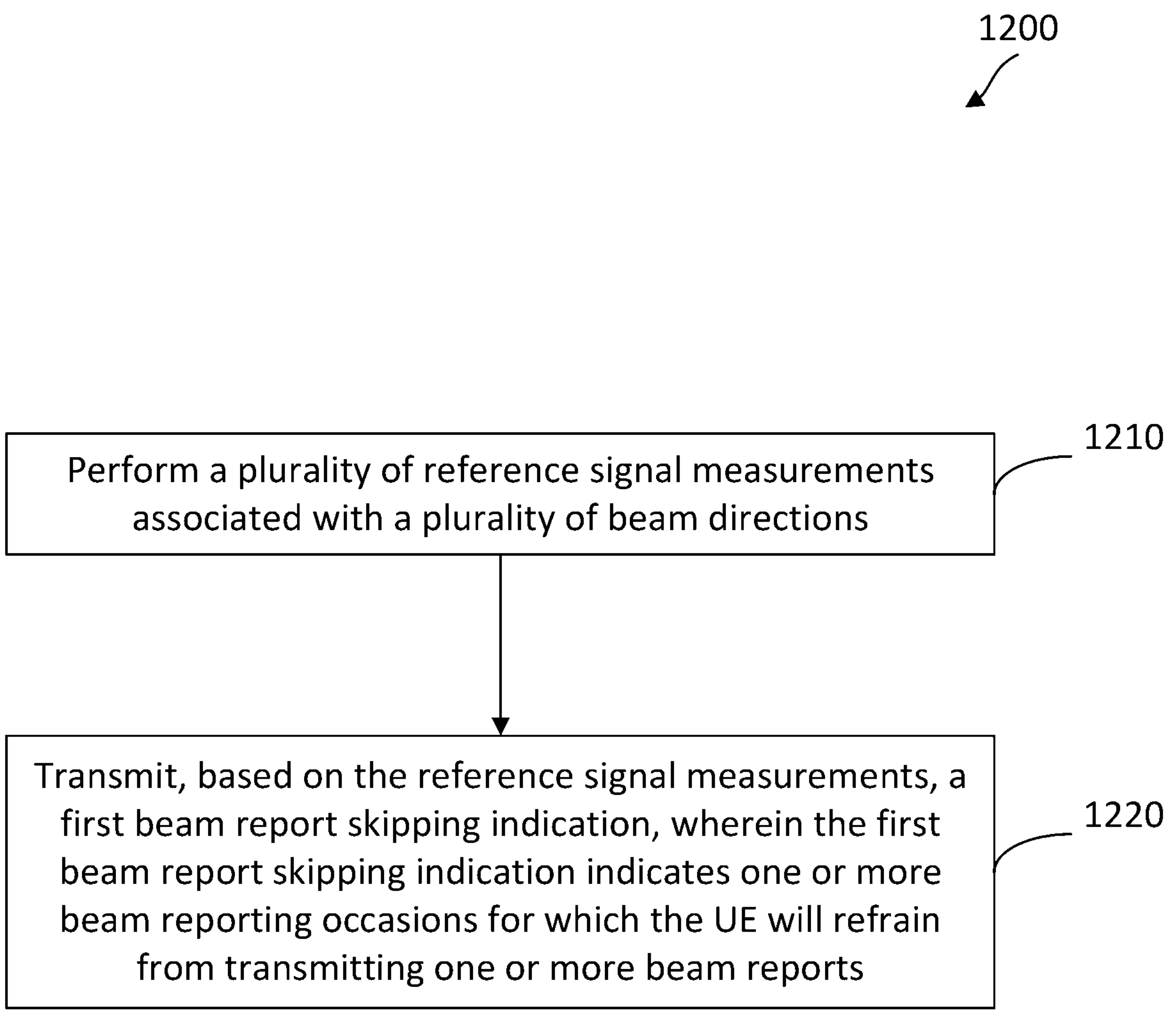
1200
Perform a plurality of reference signal measurements associated with a plurality of beam directions
1210
Transmit, based on the reference signal measurements, a first beam report skipping indication, wherein the first beam report skipping indication indicates one or more beam reporting occasions for which the UE will refrain from transmitting one or more beam reports
1220

FIG. 12

# INTERNATIONAL SEARCH REPORT

International application No.
**PCT/CN2023/100366**

**A. CLASSIFICATION OF SUBJECT MATTER**

H04W 16/28(2009.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: H04W, H04Q, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

3GPP,CNABS,CNTXT,DWPI,ENTXT,ENTXTC,OETXT,VEN,WPABS,WPABSC: beam, measure+, indication, refrain+, report, skipping, skip+, UCI

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | EP 3826197 A1 (NTT DOCOMO, INC.) 26 May 2021 (2021-05-26)<br>description, paragraphs [0012]-[0101], [0204] | 1-30 |
| A | WO 2023050419 A1 (NOKIA SHANGHAI BELL CO., LTD. et al.) 06 April 2023 (2023-04-06)<br>the whole document | 1-30 |
| A | WO 2023272710 A1 (QUALCOMM INC.) 05 January 2023 (2023-01-05)<br>the whole document | 1-30 |
| A | US 2022007207 A1 (QUALCOMM INC.) 06 January 2022 (2022-01-06)<br>the whole document | 1-30 |
| A | US 2020052753 A1 (QUALCOMM INC.) 13 February 2020 (2020-02-13)<br>the whole document | 1-30 |

☐ Further documents are listed in the continuation of Box C.  ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| **18 December 2023** | **21 December 2023** |

| Name and mailing address of the ISA/CN | Authorized officer |
|---|---|
| **CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION**<br>**6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China** | **LI,Ping**<br>Telephone No. **(+86) 010-53961602** |

**INTERNATIONAL SEARCH REPORT**
**Information on patent family members**

International application No.
**PCT/CN2023/100366**

| Patent document cited in search report | | | Publication date (day/month/year) | Patent family member(s) | | | Publication date (day/month/year) |
|---|---|---|---|---|---|---|---|
| EP | 3826197 | A1 | 26 May 2021 | WO | 2020017043 | A1 | 23 January 2020 |
| WO | 2023050419 | A1 | 06 April 2023 | None | | | |
| WO | 2023272710 | A1 | 05 January 2023 | None | | | |
| US | 2022007207 | A1 | 06 January 2022 | None | | | |
| US | 2020052753 | A1 | 13 February 2020 | EP | 3834312 | A1 | 16 June 2021 |
| | | | | WO | 2020033076 | A1 | 13 February 2020 |
| | | | | CN | 112534747 | A | 19 March 2021 |